PN-ACB-393 5

DFM

DECENTRALIZATION: FINANCE & MANAGEMENT PROJECT

Managing and Financing Rural Road Maintenance in Developing Countries

Larry Schroeder
Metropolitan Studies Program
Maxwell School of Citizenship
Syracuse University

Managed by
Associates in Rural Development, Inc.
110 Main Street, Burlington, Vermont 05401 • 802-658-3890 • Telex/957032 • FAX/802-658-4247 • BITNET/ARDBTV@UVMVM

In collaboration with
Syracuse University • Metropolitan Studies Program/Maxwell School of Citizenship & Public Affairs
Indiana University • Workshop in Political Theory & Policy Analysis

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Agency for International Development

ACRONYMS AND ABBREVIATIONS

ARD	Associates in Rural Development, Inc.
C&W	Communications and Works
ER	economic return
ESAL	equivalent single-axle load
franc CFA	West African unit of currency
HDM-III	Highway Design and Maintenance Model; Version III (World Bank)
ILO	International Labour Organization
OECD	Organization for Economic Cooperation and Development
TRRL	Transport and Road Research Laboratory
USAID	United States Agency for International Development

PREFACE

THIS paper was prepared as a companion piece to the recently released report *Institutional Incentives and Rural Infrastructure Sustainability* by Elinor Ostrom, Susan Wynne, and Larry Schroeder. That volume encompasses discussions of a wide range of infrastructure development experiences and argues that inappropriate institutional incentives provide a key to the large number of unsuccessful attempts made to develop and sustain infrastructure investments in many developing countries. The current paper narrows that focus considerably and concentrates exclusively on issues associated with rural roads. While the arguments contained here complement those made in the more general volume, the current paper can be read separately from that piece.

The rapid deterioration of rural roads is one of the more challenging issues facing many countries in the developing world today. This paper is an attempt to review what is currently known about the technical, financial, and managerial constraints that make the problem so difficult. At the heart of this difficulty is the nature of road services that make it very hard to link the utilization of roads with their management and finance. Although a significant portion of the paper is devoted to these management and finance issues, a separate section reviews what is known about the more technical aspects of rural road maintenance under the expectation that proper maintenance activities are necessary if road deterioration is to be slowed. Since the more general arguments related to institutional analysis are contained in the companion volume, relatively little space is devoted here to these same issues.

Grateful acknowledgement is given to the following for helpful comments and assistance received during the preparation of the several drafts that led to this paper: Vijay Rao, doctoral candidate in public administration at the Maxwell School, Syracuse University, for his research assistance; Jerry Miner, Elinor Ostrom, James Thomson, Louis Siegel, and Kenneth Kornher for their comments; and finally, the staff of the Metropolitan Studies Program—especially Esther Gray, the fine group at Associates in Rural Development for their assistance in preparing the earlier drafts, as well as the final version of this paper.

This work is a product of the Decentralization: Finance and Management (DFM) Project that is sponsored by the Office of Rural and Institutional Development of the Bureau for Science and Technology (S&T/RD) of the U. S. Agency for International Development (USAID). ARD is the prime contractor for the DFM project under USAID contract number DJR-5446-Z-00-7033-00 with subcontracts to the Metropolitan Studies Program of the Maxwell School of Citizenship and Public Affairs at Syracuse University and the Workshop in Political Theory and Policy Analysis at Indiana University. The positions expressed are those of the authors and do not represent the official views of the sponsoring agency.

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INTRODUCTION

ONE particular type of rural infrastructure maintenance that has recently received considerable attention, particularly by donors, is road maintenance. There are good reasons for this interest. Transportation in general and rural roads in particular are a necessity if an exchange-based economy is to function efficiently. Inputs need to be transported to production sites, and outputs must be moved to where they can be used by consumers or other producers, or they must be exported to earn additional returns. Furthermore, roads play a crucial role in facilitating social exchange and mobility as well as the internal and external defenses of most countries.

These recognized benefits of roads have led international donors to commit large quantities of funds to road and highway construction and reconstruction. As these past investments are observed to deteriorate at rates exceeding expectations, concern has mounted that policies be undertaken to improve maintenance efforts in order to sustain past and current road investments and delay replacement of this necessary infrastructure. 1 The financial implications of these efforts are tremendous. A recent review of the "road maintenance crisis" by the World Bank suggested that:

- More than one-quarter of paved and one-third of unpaved roads in 85 countries receiving roadway assistance from the World Bank already are in such poor shape as to require partial or complete reconstruction.
- Over 40 percent of currently passable paved roads are at the critical stage where strengthening is necessary to prevent structural failure that would either necessitate reconstruction or abandonment.
- It is estimated that an additional $4 to 5 billion will be necessary every year to slow future deterioration in the roads and highways of developing countries (Harral, 1987:1).

The same analysis suggests that if appropriate maintenance strategies had been implemented in the past, some of these future needs could have been avoided. Estimates suggest that the $40 billion it would now cost to rehabilitate the 25 percent of all paved roads could have been avoided had only $12 billion been spent on maintenance. This is obviously a healthy return on maintenance investment.

There is, therefore, little doubt that the problem of road maintenance is great and that the benefits from improving the situation could be significant. Unfortunately, workable solutions are difficult to specify and no definitive answers are provided here. Instead, the intent of this paper is to buttress the arguments of

[1] For a good review of the current state of road disrepair in developing countries, see Harral and Faiz (1988).

Institutional Incentives and Rural Infrastructure Sustainability (Ostrom, Schroeder, and Wynne, 1990) by drawing exclusively on experiences concerning road maintenance efforts in developing countries.

We begin by discussing the attributes of rural road services that create disincentives to effective financing and management of road maintenance. At least three factors determine whether or not maintenance actually occurs. First, maintenance must be technically feasible. Section II provides an overview of certain technical features of road maintenance (albeit from the perspective of a nonexpert in road engineering). Second, there must be resources available for financing maintenance, and the budgeting process must allocate those resources to that usage. Finance and budgeting are, therefore, the subjects of Section III. Finally, even if maintenance activities are technically feasible and the appropriate resources are available, there is no guarantee that the activities financed will result in effective road maintenance. This is the task of management—the topic of Section IV. A brief summary concludes the paper.

Road Services: Benefits and Attributes

ECONOMIC efficiency of any effort to sustain investments in rural roads requires that such investments yield benefits in excess of their costs. It is therefore useful to begin this review of rural road maintenance by briefly considering the benefits that can flow from investments in rural roads (and implicitly from their maintenance, although this narrower topic is considered in more detail below). Such a review can also provide insight into the incentives that different groups might have to sustain such investments. Unfortunately, the attributes of road services are such that ensuring that these activities are undertaken is often extremely difficult. The second portion of this section considers these service attributes.

Benefits of Roads

The benefits of improved transport facilities have been recognized by economists since Adam Smith noted that "Good roads, canals and navigable rivers, by diminishing the expense of carriage, put the remote parts of the country more nearly upon the level with those in the neighborhood of the town. *They are upon that account the greatest of all improvements*" (1776:147, emphasis added). Empirical evidence concerning benefits from road construction projects in developing countries has, however, raised questions about the direct rates of return from such investments absent other complementary and supporting policies. To provide a foundation for the subsequent discussion, we review some of the literature concerning the sorts of impacts roads are expected or have been observed to have.

The economics of road infrastructure investment are based on the argument that roads yield benefits to those using the road by decreasing the costs of transporting goods and persons. For local rural roads in developing countries these benefits generally accrue to producers of agricultural products and the transporters of such products. Two different, albeit equivalent, methods are available for estimating such benefits: consumer surplus and producer surplus. The former focuses on the transport cost savings attributable to improved road facilities. By lowering the price (cost) of transport, users of roads enjoy additional benefits and, if there is a responsiveness of demanders to this new lower price, additional travel will also be generated. The consumer surplus approach therefore focuses on the demand for transport.

The producer surplus approach maintains that improved transport facilities, by lowering the cost of transportation, effectively lower the costs of production (including the costs of marketing the produce). Hence, even though the market price of the good may not change (at least in the short run), the lowered costs of production increase the profitability of production and, assuming some responsiveness of production to prices, can encourage greater production of the good. Equivalently, the lowered transport costs can be thought of as an increase in the "farmgate" price obtained by the producer.[2]

Beenhakker and Lago (1983) demonstrate that, under a certain set of assumptions, both the consumer and producer surplus approaches to estimating the benefits of roads will lead to identical findings. The consumer surplus approach is considered more appropriate where analysts have information on road usage and estimates of transport cost savings associated with improved roads; the producer surplus approach is preferable where production data are available for the area anticipated to be affected by the road improvements. While actual application of either of these approaches has potential weaknesses (Devres, 1980:41-43), they each suggest the economic impacts that are most likely to accrue from improvements in road services. That is, investments in roads are expected to produce one or more of the following effects:

- reduced transport prices and increased use of roads;
- increased farmgate prices of produce;
- increased agricultural production and cropping intensity; and
- lower prices of agricultural inputs.

A less direct measure of the economic impact of roads can be observed on land prices. As the profitability of agricultural land is enhanced through lower costs of transporting inputs and outputs, the price of land will increase. Thus, another probable indicator of benefits from road improvements are land value increments.

Each of these effects was observed in a set of evaluations performed in the late 1970s and early 1980s by the United States Agency for International Development (USAID) (Anderson and Vandervoort, 1982). Similarly, a recent review of more than a dozen unpublished studies and reports that focused on the returns to rural road investments in Bangladesh showed that, at least in the bulk of these studies, these same impacts were observed for roads in this very poor country (Jahan, 1989).

Other factors, however, have been found to affect the degree to which these anticipated effects actually occur or to whom the benefits of road improvements accrue. As suggested above, if the road transport sector is not competitive, suppliers of transport services, rather than agricultural producers, will derive the benefits in the form of monopoly profits. Similarly, Jahan (1989) observed that where input prices are administered without accounting for transport costs, farmgate prices of agricultural inputs, e.g., fertilizer and seeds, may not be influenced by improved road transport.

Since transportation is but one factor affecting the profitability of agricultural production, it is not surprising to find that the direct economic benefits of roads can be significantly affected by the availability of other, complementary inputs to the agricultural production process. For example, if credit is not available to farmers, there may be no realization of the decreased costs of transporting such inputs as seeds and fertilizer since the farmers may be unable to purchase these factors without adequate credit. Beenhakker and Chammari (1979: 1) state that in the World Bank's experience "the main reason for not achieving forecasted economic returns (ERs) of road improvements in the past is the absence of a complementary agricultural development program." While such conclusions are not surprising, they do complicate the process of determining the extent of benefits directly attributable to road investments.

In addition to the availability of complementary inputs, the general policy environment may also affect

[2] Such transport price changes will, however, depend on the competitiveness of the transport industry. Where the industry is uncompetitive, the additional transport cost savings attributable to improvements in roads will accrue to the transport industry and may not result in increased production of agricultural outputs since actual farmgate prices will not increase. All benefits will be retained by those transporting the goods.

the degree to which benefits are actually realized from road investments. Lack of incentives due to price controls, excessive regulation of the transport industry, and inappropriate import and production restrictions on vehicles and/or spare parts all may decrease the economic impact of rural roads (Carapetis, Beenhakker, and Howe, 1984).

The USAID evaluations also determined that the impacts of investments in roads noted above were significantly greater for new roads than for improved roads since the new routes allowed transport that previously had not occurred. From an economic efficiency standpoint, however, this does not mean that improvements are unwarranted since what really matters is the net benefit from a project. So long as road improvements produce positive net benefits, they are justifiable on economic efficiency grounds.

Although rural roads in developing countries are generally seen to yield benefits, the literature is less clear on the extent to which these benefits can alleviate poverty. In part, this effect depends on the distributional impact of these returns. The summary of USAID evaluations of rural roads concluded that:

> Although the poor usually benefited significantly from rural road construction, the more influential and well-off usually benefited more because road construction reinforced existing development patterns. The disadvantaged enjoyed most of the benefits only where the roads served communities, most of whose inhabitants were poor, or where complementary services were available to the poor (Anderson and Vandervoort, 1982: 19).

Howe (1984) has conducted perhaps the most comprehensive review of the poverty alleviation effects of roads. In spite of the difficulties in gleaning income distributional implications from a variety of studies, Howe was able to reach a number of "robust" conclusions that are sufficiently important to recapitulate here. Among the conclusions reached by Howe (1984:80-81) are the following:

1. Local circumstances are extremely important to the outcomes from road investments. Extrapolating from experiences gained in one instance to other locations is dangerous.
2. The evidence does not warrant optimistic predictions concerning the ability of road investments to alleviate poverty, at least in the short run.
3. Although new roads may result in considerable increases in traffic, road improvements seldom decrease transport costs sufficiently to result in significant increases in demand.
4. Factors such as regulation of crop prices or transport services and the relative importance of transport in the final cost of a product are likely to constrain the benefits of road improvements even if the improvements lead to substantial decreases in vehicle-operating costs.
5. Because they essentially ignore personal travel, marketplace-oriented methods of estimating road improvement benefits are overly simplistic.
6. Road benefits are generally skewed towards large land owners unless coordinated public policies and actions complementary to road investments are undertaken.
7. Land tenancy conditions play a key role in determining the degree to which landless or land-poor participate in the benefits of road investments; where land ownership is relatively equally distributed, lower-income groups are most likely to derive benefits.

This set of conclusions is, therefore, quite pessimistic concerning the degree to which poverty-reduction objectives can be achieved from rural road improvement projects.

One study that reached the opposite conclusion, however, is that of Ahmed and Hossain (1988). In a comparison of Bangladesh localities characterized by well-developed versus underdeveloped infrastructure, they found agricultural incomes were significantly higher in those areas with greater infrastructure and that these benefits also improved the situation of the poor in these communities. In an earlier study of rural roads in Bangladesh, Hossain and Chowdhury (1984:79) observed that increased accessibility associated with improved roads increased the demand for transport operators who were commonly drawn from the landless class. They therefore concluded that, while the primary beneficiaries of road improvements would be landowners and traders, "the improvement in roads will absorb more and more operators in the expanding transport sector. Therefore, even if the distribution of income does not improve, the welfare of the poor will."

While there are numerous other impacts of roads including increased accessibility to other social services, such as health and education, and environmental effects (Anderson and Vandervoort, 1982), this review of the economic benefits has been undertaken in order to gain a better understanding of the incentives that are likely to influence the willingness of persons to develop and maintain rural roads. However, it is the attributes of road services that influence whether the benefits derived from these services can be transformed into an effective demand for road improvement and maintenance.

Attributes of Roads

The attributes of roads, like much jointly used rural infrastructure, make it difficult to design institutions that create incentives to promote efficient outcomes. Here we focus on the same set of attributes discussed in *Institutional Incentives and Rural Infrastructure Sustainability*, but concentrate exclusively on rural roads. On the consumption side, these attributes include: nonexcludability, joint use including nonsubtractability, measurability of benefits, and lack of choice. On the production side, the attributes include: economies of scale, asset specificity, co-production, and rate of deterioration.

Nonexcludability. The nature of roads is such that it is theoretically possible to exclude anyone unwilling to pay for the right to use a road. All that is necessary to exclude nonpayers is to control access to the roadway by installing gates and fences. Throughout history, privately financed and operated turnpikes and toll-roads have been used to provide road services.[3] While these private companies did add to the stock of transport infrastructure, they were generally unsuccessful in earning profits for their investors, largely because users avoided toll-gates and became free riders or were encouraged to use alternate modes of transport, such as canals.

The cost of collecting tolls and ensuring against free riding in rural areas of most developing countries makes the feasibility of toll roads quite unlikely. An exception to this generalization has been observed in Bangladesh where tolls have been placed on certain highly demanded rural roads for which no viable alternatives exist. On five such roads, tolls generated produced revenues to meet approximately 20 percent of the maintenance expenditures allocated to these routes (Schroeder, 1983). However, the nature of the routes is quite special; for example, some roads serve trucks that haul highly demanded construction materials, for which there is no alternative access available. Relatively few rural roads in developing countries display these attributes.

Even where toll charges are feasible, the question remains as to what constitutes an efficient price. This issue is addressed more fully in the section on financing road maintenance; to a great extent, the question rests on the subtractability attributes of road services.

Joint Use and Subtractability. Roads generally serve numerous users. The principal exceptions are roads constructed on large estates, such as sugar or rubber plantations, designed primarily to provide transport services to the trucks and equipment used on the estate. Still, public roads can differ greatly in the variety of users served in rural areas of the developing world. Certain roads may serve only a few families all of whom have generally similar characteristics; other local roads may connect villages or channel local traffic into arterial roads; finally, major roads serve through traffic as part of the overall transport network. Different terms are attached to each of these types of roadways by different donor organizations and the terms may even differ slightly across countries. For example, the first type of road (serving small groupings of users) is termed a rural local road by USAID, a Class III or farm-to-market road by the World Bank, and a feeder/collector road by Cornwell (Devres, 1980:24).[4] Organizing users to participate in the maintenance and repair of these different types

[3] For example, Adam Smith (1776:687-688) mentions the operation of toll roads and turnpikes in both England and France as well as China. For a more recent discussion of private turnpikes in America, see Klein (1985) and Newlon (1986).

[4] A fuller classification of roads, from footpaths to primary highways, is shown in Beenhakker (1987:2).

of roads will be increasingly more complex as the numbers served and the heterogeneity of users increase. Hence, designing a local institution to oversee a rural local road is likely to be much easier than for a road that serves a large number and wide variety of traffic as an integral part of the overall transportation network.

There are generally two ways in which road usage may be considered subtractable or rival. If one person's use of a road creates congestion and thereby increases others' costs of using the facility, the road demonstrates rivalry in use. Or, if one's use of the road damages its surface which, in turn, increases the costs others bear in using the road, there has been a subtraction from the net benefits accruing to other users. In either instance, unless these external costs are internalized to the perpetrators, inefficiencies result.

Of course, congestion is not a problem for most rural roads in developing countries; hence, congestion-based tolls are not justified as a method to internalize the costs associated with joint use.[5] Use-related costs, however, are another matter. Road use very well may add to the costs other users must bear because it contributes to the need for additional maintenance. The issue then is to determine the extent of these additional maintenance costs and devise a system to impose use-related charges reflecting such costs so as to achieve an optimal level of use of the road. As is discussed in more detail in the following section on the technical features of road maintenance, the amount of additional cost associated with an additional pass over the road by a vehicle will depend on several variables, the most important of which are the type of vehicle (including its weight and type of wheels or tires) and the type and condition of the road surface. Thus, a heavy truck on a waterlogged earth surface will impose considerably greater maintenance costs than will a bicycle rickshaw traveling on hard-surfaced road. In the latter case, there is essentially no subtractability of services imposed on other users. There is, of course, still the difficulty associated with measuring these costs and apportioning them equitably.

Measurability of Benefits. As noted above, there are two, logically equivalent approaches generally used to estimate economic benefits of road projects: consumer surplus and producer surplus methods. Other, more rapid, appraisal techniques have also been developed (Beenhakker and Lago, 1983, and Anderson and Vandervoort, 1982). Perhaps the most complete list of alternative evaluation techniques is provided in Beenhakker (1987) where seven different approaches to the task of evaluating potential net benefits of road projects are described. The approaches differ in the sets of assumptions that are used and, in turn, in the sorts of data that must be available for the various approaches. Eighteen different types of data are indicated as being necessary for application of the entire set of alternative techniques. This emphasizes that the estimation of benefits is not a trivial task.

Furthermore, there are tradeoffs between the amounts of data necessary to carry out the estimates of benefits, and the factors that must be assumed away. For example, when using the producer surplus approach to estimating benefits it is common to ignore lower vehicle operating costs for nonagricultural uses of an improved roadway; including such factors requires additional information concerning the extent of these uses. In addition, there are other factors that are nearly always ignored in the estimation of economic benefits. One particularly important factor is the time-savings associated with improved transport. Most commonly, it is assumed that since wages are so low, the opportunity costs of time are minimal in a developing country. Yet some observers argue that the value of time is not trivial even in a low-income country, since observations show that persons are quite willing to pay to save this resource (Anderson and Vandervoort, 1982:J2).

Of particular relevance to the measurement of road improvement benefits are assumptions concerning maintenance. Benefits of roads are generally projected 20 years into the future and commonly assume that necessary maintenance will occur. Since the benefits are projected under an assumed state of the road, if the facility is not maintained and, there-

[5] This is not, of course, the case in many cities in the developing world where congestion-based fees for the right to use a roadway are fully justified on economic efficiency grounds.

fore, is allowed to deteriorate, the projected benefits will not arise. Of course, the projected costs associated with maintenance also will not be incurred; nevertheless, the overall capital investment is less likely to yield benefits in excess of the total project costs. As Beenhakker (1987: 216) notes, "Review of project completion reports reveals that in a large portion of completed projects with rural road components, insufficient attention was paid to their maintenance during project preparation and/or implementation."

Still, measuring benefits of road maintenance is not a simple task. The Permanent International Association of Road Congresses' Economic and Finance Committee reported in 1979 that "We know relatively little about the *benefits* of maintenance, for instance: reductions in speed with road conditions; rates of vehicle deterioration; accident rates"(p. 33; italics in the original). Hence, while it is difficult to ascertain the benefits of roads, measuring the benefits of road maintenance is even more complex. This is particularly true if few instances of sustained maintenance efforts are observable in any locality.

Measurability of the incremental costs associated with an additional vehicle passing over a road surface is also a difficult task. The type of traffic and its loading will affect maintenance needs; the original design of the road (for example, how well it will allow drain-off of standing water) will influence the marginal costs of additional traffic during rainy periods; the construction techniques applied (for example, how well the subsurfaces are compacted) will affect the marginal costs of using the road; and the effectiveness of maintenance techniques employed is also important.[6]

Degree of Choice. As with most capital infrastructure in developing countries, once roadways are in place, little further consumer choice is provided (other than to choose between travel over two competing roads that lead to the same destination). The primary choices involving roads arise when new roads are to be sited or when one of several alternative routes is to be upgraded or improved. In fact, in at least some countries, roads or paths have been in place for many years, in which case the only choice concerns which route(s) to upgrade.

Local information and a full consideration of the benefits of the alternative routes are necessary for efficient choices to be made. For example, if transport time-savings information is not used in the evaluation process, it is quite possible that inefficient decisions will be made. To ascertain such information however, requires local inputs rather than simply observing maps showing agricultural production within the "zones of influence."

Similarly, there may be two routes, R1 and R2, from point A to B. If, for example, route R1 was a slightly more circuitous and therefore a bit longer than route R2, pure cost minimization would suggest that R2 be upgraded rather than R1. However, such a decision algorithm would ignore local preferences and could lead to inefficient outcomes. It could be the case that route R1 has been used for centuries to get from A to B and handles much local traffic. Purely centralized decision-making without considering local preferences may lead to a less efficient outcome, as well as less willingness on the part of the local population to maintain the upgraded route.

Economies of Scale. Economists have long recognized that roads and bridges exhibit economies of scale. Indeed, both the classic examination of the problem of decreasing costs by Hotelling (1938) and the even older examination of decreasing costs by Dupuit (1844) used the problem of bridges to illustrate the arguments. The essence of these economies of scale is that once a facility is in place, the additional costs associated with using the facility continue to decline with additional users up to the point that congestion occurs (assuming that additional maintenance costs are negligible). This is because there are substantial fixed costs associated with construction of the facility; once the facility is in-place, it is uneconomical to attempt to ration the facility through pricing, since marginal costs of usage are zero.

This argument, which leads to the conclusion that noncongested facilities be zero-priced, is of course based on the assumption that the facility is in-place and that there are no marginal maintenance costs

[6] For a modeling of these factors and illustrations of the difficulties of calibrating the models, see Paterson (1988).

associated with additional use of the facility. The costs to society of building the road or bridge are, obviously, not zero. For this reason, it is essential that determination of the benefits anticipated from a facility be reasonably accurate lest inefficient investments be undertaken. When prices are not charged for marginal usage of a resource, it is more difficult to ascertain information on the value of the facility.[7]

Another instance of potential economies of scale arising in the case of roads concerns maintenance equipment and organizations. Certain types of road maintenance equipment entail fairly substantial investments in highly specialized machinery, such as large mechanical graders for maintaining earth roads. In such instances, economies of scale can be attained through consolidation of the authority over the use of road maintenance equipment. Other aspects of earth road maintenance do not require such substantial initial investments; therefore, economies of scale will not arise. The conclusion, then, is that efficient organization of road maintenance activities depends crucially on the nature of the equipment necessary as well as on the types of activities that need to be carried out.

Asset Specificity. As noted in *Institutional Incentives and Rural Infrastructure Sustainability*, certain assets used in road construction and maintenance are such that they do not have alternative uses, whereas others can easily be redeployed into other activities. With highly specific assets, it is less feasible to rely exclusively on private sector contracting arrangements to produce publicly provided roads. This argument is closely linked to the economies of scale attribute noted above. A highly specific piece of capital is less likely to allow its owner to enjoy the benefits of any economies of scale from its use; therefore, a private entrepreneur will incur greater risks by investing in such equipment. When roads are designed in ways that lessen the need for such specialized equipment, there is a greater likelihood that efficiencies associated with private enterprise production can be enjoyed.

Co-Production. The concept of co-production is most relevant to services that require the active participation of individuals to produce the services. For example, education services are not produced without the active participation of the individual being educated. In the case of roads the concept of co-production is probably less relevant than is co-consumption. That is, in order for some benefits of roads to be derived, the consumer of road benefits must also put forth some effort. Thus, the farmer using a road to transport his produce to market is not a passive consumer of the road. For road benefits to be realized (i.e., consumed), the user also must participate. Because of this important attribute of roads, the siting and design of the facility should involve that active participation of the users if the most effective facility is to result.

This aspect of the utilization of roads demonstrates again the great importance of complementary activities in determining the overall benefits of road projects. As cited above, this has been a principal finding of past evaluations of rural road projects. If roads are to yield increased production of agricultural output by lowering the costs of transporting fertilizer and seeds to the farmer, it is absolutely necessary that these inputs be available. Similarly, consumption benefits of improved health due to lower costs of transportation to health centers assume that these centers exist and are producing beneficial services. Again, local knowledge concerning these factors and the demands for them (including the fact that health centers and schools themselves require co-production to yield benefits) can assist in the road planning and design process.

Rate of Deterioration. Deterioration of certain types of roads, particularly hard-surfaced highways, is an especially slow process that cannot be easily detected. At the same time, maintenance efforts to ensure that water does not penetrate into the road subgrade are crucial to the usable life of the road. Ensuring that such efforts are undertaken on hard-surfaced roads is a more difficult task than in the case of earth roads, where it soon becomes obvious that if water is allowed to stand on the road surface, vehicles create potholes that eventually raise the costs of all road users. Still, as is discussed in the following section on the

[7] This argument is made forcefully in Minasian (1979), who argues that without such pricing mechanisms a misallocation of resources will result.

mechanics of road maintenance, even with earth roads there are various types of maintenance activities that also do not immediately reveal payoffs. This lack of visibility compounds the problem of ensuring that maintenance activities are carried out and that resources are mobilized to support such activities.

Conclusion

Effective rural road development and maintenance is made particularly complex by the nature and attributes of road services. Roads exhibit many characteristics of imperfect public goods. While nonpayers can be excluded, the costs of doing so generally exceed the revenues obtained, making private provision or even public use of prices as indicators of demand impossible to use. Furthermore, with multiple users and slow rates of deterioration it is difficult to ascertain the marginal costs of an additional user. Similarly, fully measuring the benefits of a road is not an easy task, particularly since the *ex post* benefits of a road may depend heavily on complementary inputs and overall public policies. All of these factors mean that designing institutions to carry out effective road development and maintenance is exceedingly problematic.

Technical Features of Road Maintenance

UNLIKE the institutional and financing issues associated with road maintenance, the engineering issues appear to be well understood and, while extremely complex, are technically solvable. There is no intent here to provide a complete discussion of the engineering aspects of road design and maintenance; however, it is useful to review several aspects of road design and maintenance activities in order to better understand the issues associated with designing institutions for financing and managing road maintenance.

Before turning specifically to road maintenance activities, it is useful to recognize the complex linkages between road construction, maintenance, and road usage benefits. An informal but useful model showing these relationships is presented in Harral, Fossberg, and Watanatada (1977). As noted there, the costs of providing a road include both construction and maintenance costs; the benefits of a road take the form of decreased road-user costs. These costs (and benefits) are, however, highly interdependent. Construction costs depend on the environment, the available technology, the standards of both pavement quality and geometric design (e.g., rounded curves versus square corners) that are to be achieved, and the prices of inputs. Maintenance costs depend on the amount of deterioration of the surface and subsurface of the road, the maintenance standards that are to be attained, the available technology, and the prices of inputs. Since road deterioration depends on the pavement standards used in the original construction as well as traffic usage and the environment, maintenance costs are in part a function of construction costs. In addition, since current maintenance costs depend in part on deterioration of the road surface, which in turn is affected by past maintenance, maintenance costs at any point in time are a function of past maintenance. Road-use costs depend on traffic volumes, the types of vehicles using the roads, the geometric design standards used in the original construction, surface condition, and the prices of inputs to road users. Again, there are obvious interdependencies since surface condition will depend on both the original construction and current and past maintenance.

The model suggests the complexities involved in road maintenance decision-making, as well as detailing the interrelationships between road design, construction, and maintenance. In the remainder of this section, we first review the maintenance activities for different types of rural road surfaces and then elaborate on experiences concerning the design, construction, and maintenance relationships. The section closes with a discussion of the perceived and observed costs and benefits of these maintenance activities.

Rural Road Maintenance Activities

First, it is important to recognize that, as with most infrastructure maintenance, road maintenance is not intended to prolong the life of a road into perpetuity. Roads of any type will deteriorate over time due to the twin forces of aging and use. The objectives of maintenance, therefore, are to lessen the deterioration effects of these two forces while also providing for increased service performance of the road in the short run.

From an engineering standpoint, there is a set of activities that are necessary over the life of a road. While the terminology is not always the same, the literature generally recognizes the following types of required activities:

- routine maintenance;
- periodic maintenance;
- emergency or special maintenance;
- rehabilitation or betterment; and
- reconstruction.

Optimal timing of these activities depends primarily on climate, traffic levels, and the original quality of construction; the specific activities to be carried out depend primarily on the type of road surface.

Unpaved Roads. For an unpaved (i.e., earth or gravel) road, routine maintenance must be conducted throughout the year if the integrity of the road is to be sustained. Generally speaking, these activities can have two effects. First, they can yield immediate consumption benefits to current users by improving the road surface. Second, the activities can increase the long-term sustainability of the road by ensuring that the roadbed or subgrade of the road does not weaken. This is particularly the case in climates where there is considerable rainfall, since saturation of a road's subgrade with water can lead to an overall failure of the road.[8]

The importance of the role of water to road effectiveness is emphasized by the Organization for Economic Cooperation and Development (OECD) (1973a:8), which notes that "Water affects the construction of the highway and its behavior throughout its lifetime; it is therefore no exaggeration to say that water is the fundamental problem of road engineering." Numerous factors affect the water content of the subgrade including soil compaction, soil characteristics, waterproofing of the road surface and the shoulders, and the water table level in the subsoil. In addition, the climate will affect the influence water has on the structural soundness of the road; e.g., freezing temperatures can have profound effects on the stability of the road surface. Consequently, the role of multiple variables greatly complicates the models needed to understand the effects of water on road effectiveness.

Routine maintenance of earth roads typically includes the following activities:[9]

- filling and compacting potholes;
  maintaining the correct surface camber to ensure water runoff;
- dragging or shallow blading to remove traffic-induced corrugations in the road surface;
- putting vegetation from shoulders to facilitate water runoff;
- repairing any erosion channels formed on the roadway, shoulders, or ditch slopes after rains; and
- cleaning silt and waste materials from culverts and bridges to ensure free flow of water.

For road maintenance to be most effective, regular inspections of the road are also necessary. OECD (1973b:27) suggests that inspections should be conducted monthly as a minimum and concludes that for roads with a small volume of traffic, "the greatest part of maintenance expenses will be allocated on the basis of routine inspections."

While none of the activities listed above is technologically complex and only blading and perhaps compaction are facilitated by mechanized equipment, the activities are absolutely necessary if the earth or gravel road is to avoid rapid deterioration. If the correct surface camber is not maintained, water may stand on the road surface and vehicular traffic will

[8] For a more complete discussion of the deterioration of unpaved roads, see Paterson (1988).

[9] See Beenhakker (1987:153) or Paterson (1988:63).

soon create major potholes that impede subsequent traffic flow. Standing water is also much more likely to saturate the subgrade, causing the road (particularly if it was not properly designed and constructed initially) to lose its strength thereby contributing to deterioration of the road surface. For this reason, it is crucial that waterways and culverts be kept clear to avoid standing water that will seep into the subgrade.

In addition to routine maintenance of earth roads, periodic maintenance is also necessary on the road surface every few years. The most common forms of periodic maintenance include regravelling of gravel road surfaces, deep blading to restore the shape of the road and ditches to facilitate proper water runoff, redecking bridges, repainting signs, etc. Many of these activities can be delayed and their costs diminished by proper application of the routine maintenance activities noted above. Nevertheless, they will have to be undertaken periodically lest the road reach a state of deterioration where even the routine maintenance activities are no longer beneficial.

Emergency maintenance must also be recognized as part of an overall maintenance regime even though such activities cannot be planned. These activities include repairs to road surfaces, bridges, or culverts necessitated by unforeseen events, commonly due to natural disasters such as heavy rains or rockslides. Beenhakker (1987:154) notes also that sometimes the original design or construction of a road is such that emergency repairs are necessitated; he advocates that such "maintenance" really be considered a part of the original construction activity. In any event, provision of emergency repairs must be part of the overall maintenance plan because if they are not forthcoming, routine and even periodic maintenance activities will be ineffectual.

Rehabilitation is considered an even more thorough and complex task than periodic maintenance of earth roads and includes reconstruction of the road subgrade and drainage facilities. This activity, which may be necessary only every 20 years or so if proper routine and periodic maintenance are undertaken and the original design and construction of the road was adequate, is considerably more expensive and technologically complex. Road betterment, which for earth roads commonly means application of some type of hard surface to the roadway or perhaps widening of the roadway to allow increased traffic flow, is closely related to rehabilitation. Again, there is an interdependence between road rehabilitation and optimal levels of routine maintenance. If roads have deteriorated too badly, no level of routine or even periodic road maintenance can yield benefits, and total rehabilitation of the roadway will be necessary. In the World Bank's recent assessment of road conditions throughout the world, it was estimated that approximately 33 percent of all unpaved main roads in 85 countries were in such poor condition that "either partial or full reconstruction" will be necessary before normal maintenance can be effective. The situation is most severe in South Asia where it is estimated that 55 percent of the nonpaved road surfaces have reached this condition (Harrall and Faiz, 1988:6-7).

Paved Roads. The same general set of activities and tradeoffs characterizes the maintenance of paved roads. Deterioration of paved roads occurs over time, at first very gradually, and subsequently at quite rapid rates, especially in the absence of adequate maintenance. For this reason, detection of the need for maintenance may be even more difficult for paved than for nonpaved surfaces where lack of maintenance, especially in rainy climates, will rapidly lead to the formation of potholes and deterioration in the quality of road use. How quickly a paved surface deteriorates depends primarily on the paving material used, although all paving surfaces will deteriorate over time, first requiring patching and resealing and ultimately requiring full overlay of the surface.[10]

Some aspects of routine maintenance of paved surfaces are identical to those of unpaved roads: cleaning culverts, controlling vegetation in ditches, ensuring proper drainage from the road shoulder, etc. In addition, any potholes that develop should be patched immediately to halt further deterioration.

Periodically, the full width of the pavement will need to be sealed to prevent seepage of water under

[10] Again, see Paterson (1988) for more details on the deterioration of paved roads as well as further discussion of the several different types of maintenance activities to be undertaken.

the road surface, which would lead to more rapid breakup of the pavement. The timing of this activity depends on road use, climate, surface type, and quality of original construction. Full resurfacing and possibly strengthening of the highway will eventually be necessary, even if the road is periodically resealed. However, such rehabilitation of the road can be delayed by the timely application of sealants, coupled with an effective routine maintenance program.

In general, there is considerable knowledge as to what activities ought to be carried out to maintain paved and unpaved roads, and the activities themselves are not terribly complex. At the same time, the specific dynamics of road deterioration are quite complex since deterioration involves the interaction of numerous factors, only some of which can be predicted accurately. For example, there is apparently considerable difference in the rutting and subgrade deterioration effects of solid-wheeled carts versus vehicles using pneumatic tires (Swaminathan and Lal, 1979:22). Hence, for rural roads where both types of vehicles are likely to use the roadway, predictions of both traffic composition and volume are important to developing appropriate design and maintenance regimes. Thus, while general modeling such as that of the World Bank's Highway Design and Maintenance Model (Paterson, 1988) is extremely useful, each site's specific circumstances need to be considered in detail if road maintenance is to be effective. Road design, construction, and maintenance relationships are particularly important in this regard.

Rural Road Design, Construction, and Maintenance

As emphasized in the introduction to this section, rural roads provide an excellent example of the choices complicating infrastructure investment decisions. Consider the possible improvement of surface transport between points A and B. Numerous design choices will be faced. There may be several alternative routes that could be improved, each of which is likely to be associated with different benefits and costs. Similarly, for any single route there will be several potential road configurations that will also vary in terms of costs and benefits. For example, an all-weather road will likely entail significantly higher up-front construction costs but will be passable throughout the year (which may or may not mean significantly greater benefits, depending on the demand for the road) and will require a different time stream of maintenance efforts. Hence, the need for maintenance will be affected by the outcome of the design activity. It is, therefore, crucial that maintenance requirements be considered during the design phase.

Construction, too, will affect the need for maintenance. Even though a particular road standard is designed with maintenance requirements in mind, if that standard is not attained in the construction process, the efficacy of maintenance regimes can be undermined. For example, based on expected traffic flows, soil composition, climate, and construction and maintenance costs, road planners may determine that a bituminous-surfaced road is most appropriate in that it would yield the largest net benefits. However, when the road is constructed, if the subgrade is not built to design standards or the bituminous surface is put down at less than the thickness specified in the plans, the correctly predicted traffic flows may soon break up the road surface and/or cause a failure in the subgrade, and the road will fail regardless of how well-planned the maintenance was.

Just as problematic and certainly more difficult from the standpoint of modeling, is the fact that the effectiveness of and payoffs from road maintenance at any point in time can be dependent upon maintenance activities both prior to and subsequent to that point in time. More formally, the payoffs of road maintenance at time period *t* will depend on the effectiveness of maintenance prior to time period *t* as well as continued maintenance subsequent to *t*. Unlike some regenerative natural resources, failure to maintain the road results in cumulative deterioration, which means that even if a proper maintenance program is instituted at time *t*, the state of the road may already be so deteriorated that the maintenance cannot restore the investment to its optimal state or even to a passable state.

Because of the complexities involved in road maintenance decision-making, factoring out the real effects of road maintenance is difficult. There have been, however, some efforts at determining the costs and benefits of this activity. We therefore close this section with a brief review of the findings of this work.

Impacts of Road Maintenance Activities

Ideally, for economic efficiency one would devise an optimal maintenance strategy based on the costs and benefits of road maintenance. However, as the preceding discussion clearly indicated, no single strategy is likely to be applicable for all roads in all locations. The complex relationships between design, construction, and maintenance (including the effectiveness of past maintenance), together with the crucial roles played by local climatic and soil conditions and different levels and composition of traffic flows, mean that each case must be considered separately. The following paragraphs review some of the evidence that has been gathered in several case studies of road maintenance strategies.

Probably the most comprehensive set of evidence on road deterioration and design of maintenance strategies has been collected in conjunction with the development of the World Bank's Highway Design and Maintenance Model, which is now in its third version, HDM-III. The HDM study is fully documented in five volumes, including Chesher and Harrison (1987); Watanatada, Dhareshwar, and Rezende-Lima (1987); Paterson (1988); and Watanatada, Harral, Paterson, Dhareshwar, Bhandari, and Tsunokawa (1987; two volumes). A major contribution of this model is that it includes both the cost and benefit sides of maintenance activities. Much of the engineering literature focuses almost exclusively on what maintenance activities are necessary to retard deterioration of roads without consideration of the benefits that such activities may or may not yield.

The HDM-III model allows the user to stipulate alternative maintenance and design strategies. Then, using prespecified projections of vehicle traffic by class and loading along with predictions of road condition changes and vehicle operating costs, it determines the total costs (to road users as well as of road construction and maintenance) of these design and maintenance strategies. Calibration of the model was based on data collected in a variety of settings. The relationship between vehicle operating costs and road characteristics and roughness was based on studies in Kenya, Brazil, the Caribbean, and India. Field studies in Kenya and Brazil provided information on road deterioration.

Hide and Keith (1979) studied the relationship between road improvements and vehicle operating costs, showing how the costs for operating different types of vehicles (cars, light commercial and heavy commercial vehicles) declined with bituminous road surface improvements in St. Vincent. When combined with the costs of routine annual maintenance and periodic resealing, the results indicated that rehabilitation costs could be recouped within one year on roads carrying more than 300 vehicles per day, while extremely low volume traffic roads would require considerably longer time to recover the costs, e.g., five years for roads with only 100 vehicles per day and twelve years for those handling 50 vehicles daily.

Another analysis of maintenance policies on hard-surfaced roads was based on evidence collected in Egypt (Bradmeyer, et al., 1979) concerning optimal asphalt concrete pavement overlay policies on different classes of roads (primary, secondary, and tertiary). Rates of return were estimated for ten different policies regarding relative frequency of overlay activities, thickness of the overlays, and differences in each of these for different classes of road. The results indicated that the greatest economic return would be achieved from policies specifying frequent light overlays on primary roads (which were already considered structurally sound) and infrequent but heavy overlays on secondary and tertiary roads (where additional structural strength was needed to meet future anticipated increases in traffic).

Jones and Robinson (1986) provide analyses of several maintenance strategies for unpaved roads, based primarily on experiences in Kenya and Ghana. One portion of their analysis emphasizes an often ignored aspect of road maintenance—maintenance of equipment—and stresses the importance of equipment availability (or lack thereof) on choice of road maintenance strategies. Because of the lack of spare parts or inadequate maintenance, the existence of mechanized maintenance equipment within an area does not mean that it is available for use. For example, motorized road graders in Kenya were observed to be available for use only 25 to 50 percent of the time. On the other hand, motor tractors were available for 72 percent of the time in eight test sites in the same country. This is partly due to the greater overall availability of tractors and parts, but it can also be attributed to the fact that tractors are simpler to repair.

Jones and Robinson show that whereas tractors with towed graders are less efficient than motorized grader units (by approximately one-half), the much greater availability of tractors makes the two alternatives approximately equal in usable efficiency. They estimate that a savings of approximately US$65 per kilometer of road would be achieved by substituting tractor/towed grader units for motorized graders (although some of the latter units would still be required to rehabilitate badly deteriorated roads for which light, towed graders would be ineffective).

The final portion of the Jones and Robinson analysis focuses on optimal grading frequency using a computer model developed by the Transport and Road Research Laboratory (TRRL) and data from Kenya, Thailand, and Papua, New Guinea. The analysis considers both the costs of road grading and the costs of vehicle operation (by various types of vehicles calibrated according to local traffic composition). Each additional grading increases grading costs, but simultaneously decreases vehicle operation costs. The results reveal the sensitivity of the findings to traffic levels, traffic composition, and cross country differences (which include differences in climate and type of unpaved road surface). Generally, for roads carrying very light traffic, i.e., less than 50 vehicles per day, one grading per year is sufficient, whereas for roads with 100 vehicles per day, the optimal grading frequency ranged from once per year in Thailand to three times per year in Papua, New Guinea (where annual rainfall is considerably greater than in either of the other two countries and different materials are used for the road surface). As the authors note, "This illustrates the problem of applying conclusions drawn in one country to conditions in another country or even to a different road in the same country" (ibid., 6). The implications of this finding for the overall decentralization theme of this project are significant.

As was mentioned in Section II, it is harder to find hard evidence on the explicit rates of return to different types of investments in unpaved road maintenance than it is to obtain indicators of their costs. One extensive analysis of the returns to routine and periodic maintenance of gravel and earth roads as well as tracks was carried out in conjunction with the World Bank/TRRL Kenya Road Transport Cost Study (Faiz and Staffini, 1979). The study included analysis of vehicle operating costs for light vehicles, single unit trucks, medium truck trailers, and heavy truck trailers as well as road deterioration characteristics (associated with vehicular traffic levels and composition) on each of the three types of unpaved road surfaces. Routine maintenance policies included drainage and vegetation control, surface dragging, and shoulder maintenance; grading of all surfaces and regravelling of the gravel surfaces were considered periodic maintenance practices. By estimating vehicle operating cost savings under policies that included and excluded routine maintenance, it was possible for the authors to estimate the rates of return of routine maintenance separate from that of periodic maintenance. A very high internal rate of return of 74 percent was computed for routine maintenance activities (which included provision for the initial capital costs of maintenance equipment and work-shop, spare parts, buildings, and technical assistance, as well as the recurrent routine maintenance expenditures). Even limiting routine maintenance to the most important 66 percent of the 5300-km road network was found to yield a rate of return of 63 percent. The results were also very insensitive to changes in assumptions concerning the expected life of maintenance equipment or the effects of increased maintenance costs.

The analysis also considered optimal policies concerning gravelling and regravelling, and found that gravelling an earth road to make it passable throughout the year was economically justified if the average daily traffic on the road was 45 to 60 vehicles per day. This finding resulted because a gravel road needed to be graded less often than an earth road; for example, at 90 vehicles per day a gravel road would require only two to three gradings per year to achieve optimal output, whereas an earth road would require 12 gradings. A 17-percent rate of return from regravelling was computed for roads on which routine maintenance was carried out.

These findings suggest that developing countries can achieve significant returns from investments in rural road maintenance. However, for such investments to be made, sufficient funding must be available and management practices must be conducive for the activities to occur.

Financing Road Maintenance

MOBILIZING the resources necessary to finance road maintenance is of paramount interest in most developing countries. As with finance questions in general, this topic can be considered from both a conceptual or theoretical view and from the standpoint of what has worked or might work in a developing country. In this section, we begin by considering the conceptual issues, emphasizing the objectives to be sought when financing instruments are designed. We then turn to a consideration of the various types of financing schemes that might be used to satisfy these objectives. The section closes with a discussion of the issue of budgeting those resources that have been raised. Since we are particularly interested in issues associated with maintenance of local roads, each of the subsections contains some reference to the special issues raised in local government finance. Unfortunately, as the review makes clear, local funding of roads and road maintenance has received relatively little study.

Theoretical Objectives of Road Maintenance Finance

As outlined by Ostrom, Schroeder, and Wynne (1990), it is desirable that the instruments used to finance infrastructure development and maintenance yield adequate and growing revenues, be equitable in their impacts, be relatively economical to administer fairly, be politically acceptable, and affect economic choices in as neutral a manner as possible. The discussion in this subsection focuses primarily on the first and last of these principals. Economically efficient mechanisms are likely to be deemed equitable on benefit financing grounds and, therefore, are unlikely to face extreme political opposition. Unfortunately, it is also the case that these financing instruments may be incapable of achieving revenue yields that meet the full costs of road provision, at least if rural roads are considered independently from the full array of rural and urban roads. Hence, at the heart of the theoretical discussion of road financing is ascertaining how an adequate amount of revenues necessary to meet these costs might be mobilized. The primary difficulty with crafting efficient and adequate road financing instruments arises in the area of revenue administration, a subject considered in the discussion of actual financing instruments.

Road-Use Costs. Since revenue adequacy of resource mobilization efforts is one major concern, it is useful to begin the discussion by considering the various types of road-use costs that need to be covered. Costs can be differentiated as those borne directly by the user, those borne by the road supplier (the public body providing the road service), and external costs borne by the rest of society (see Walters, 1968:22-24). Our focus on finance makes road provision costs and any external costs associated with road use of particular interest.

In order to achieve an efficient allocation of resources, the price for using a road should be equated to the marginal costs of road usage. But not all of the costs of road provision are encompassed in marginal costs. Costs include both fixed and variable costs;

fixed costs by definition are not affected by an additional vehicle passing over a road. Fixed costs include the costs of supplying the road as well as maintenance costs that are necessary regardless of the use of the road. Among the activities included in the fixed maintenance cost category are cutting vegetation from the shoulders or cleaning silt from bridges and culverts. The marginal costs of road usage include (in addition to the operating costs of the vehicle itself) any road maintenance costs attributable to each additional use and the external costs that one person's use of the road imposes on other users.

There are several types of external costs that are theoretically relevant; these include pollution costs associated with motor vehicle use, accident costs, congestion costs, and the additional road-use costs imposed on other users as one's use of the road hastens its deterioration and, hence, the costs other users must bear. Analysis of road transport in developing countries has generally ignored pollution and accident costs despite their potential significance, especially in urban areas. Congestion costs are obviously of paramount interest in many major cities of the developing world; they are generally irrelevant, however, on little-traveled rural roads. The one exception to this concerns nonmotorized vehicles that may significantly impede the flow of motorized traffic on narrow rural roads or contribute to accidents.

Even without any congestion, one vehicle's use of a road can affect road-use costs for subsequent users since the first vehicle can add to the deterioration of the road. As stated by Newbery (1987:7), "Since vehicle operating costs increase with roughness, the passage of an extra ESAL [equivalent single-axle load] over a road has two effects—it advances the date at which maintenance will be required and hence raises the costs borne by the highway authority (the traditional pavement costs), and it raises the vehicle operating costs of subsequent vehicles, thus creating a road damage externality for subsequent road users." Newbery (1987:9) goes on to argue that the increased vehicle operating costs due to others' use of the road are substantial and may be comparable in importance to the costs of the pavement. Hence, efficient financing mechanisms should capture such externalities so that the vehicle user is forced to recognize the full costs of his or her actions.

This argument can be a bit misleading since it implies that efficient pricing of roads would require that vehicle operators pay for the costs of the additional maintenance that their use of the road requires *plus* bear the additional costs that lack of this maintenance would impose on subsequent travelers. If no additional maintenance would be forthcoming, an obvious externality would be imposed on subsequent users of the road. On the other hand, if a maintenance worker was assigned to follow each and every vehicle and put the road back into the condition it was in prior to the vehicle's passage, the costs of this maintenance should be borne by the road user. This cost is not an externality in the classical sense of the term; instead, it is analogous to efficient pricing of a good or service, i.e., price equal to marginal cost. Furthermore, if applied, no externality would be imposed on subsequent users of the road.

Since roads are obviously not maintained immediately after the passage of each additional vehicle, the present value of these future expenditures for maintenance will be less than the ultimate budget outlay. Furthermore, the additional costs borne by subsequent users of the road will occur as soon as such vehicles pass over the road surface. A question that arises is what user fee should be paid by road users today, such that the fee is just equal to the full marginal cost of future road maintenance and external costs borne by subsequent road users? Newbery (1987) presents an extremely interesting theoretical result, indicating that under certain conditions, the efficient road-use charge is exactly equal to the average cost of maintenance per ESAL. The theorem is based on the important assumption that a road surface will be rehabilitated after it reaches a predetermined level of roughness (which may or may not be the optimal level of roughness). With additional traffic flow, the roughness of the road increases, thereby increasing the operating costs to all subsequent traffic; however, if the rehabilitation policy is in force, this also means the time of rehabilitation will be moved forward. The theorem shows that for a road with uniform age distribution, the marginal social cost of an extra vehicle will be equal to the average cost borne by the highway authority.

The implication of this finding is that those vehicles doing greater damage to a roadway should pay proportionately more for road maintenance, but that under the prespecified rehabilitation policy, it is not necessary to estimate the costs that an additional vehicle places on subsequent users of the road. All that is necessary is an estimate of the proportion of rehabilitation costs attributable to particular types of vehicles. These proportionate costs will depend in part on the weight of the vehicle. Experimental findings have shown that the damaging power of a vehicle is approximately the fourth power of its axle load; hence, the efficient price to be charged on heavier trucks may be 10,000 times greater than that imposed on medium-weight automobiles.

At the same time, it must be stressed that the theorem applies only to the additional maintenance costs attributable to road use and does not include maintenance costs associated with nonuse factors such as weather. Since weather and natural aging may influence both routine and periodic maintenance costs, mobilizing resources simply on the basis of additional maintenance costs associated with road use will be insufficient to meet the total costs of maintaining a road.

Newbery also notes that the theorem does not apply for unpaved roads where predetermined maintenance strategies are imposed without regard for the condition of the road. For example, if a nationwide strategy of blading a road once each year is followed without regard for the specific condition of the road, "road damage externalities may be appreciable" (Newbery, 1987:11). In this instance, the maintenance policy is not one of road surface-determined rehabilitation; if, by blading only once a year, road conditions deteriorate badly in response to vehicle usage (and therefore increase operating costs to subsequent users), an efficient road-use charge would result in revenues in excess of the cost of annual blading.

The theory of efficient user charges has implications for decentralized financing of rural roads. Since road deterioration differs by the type and condition of the road surface as well as weather conditions, local time and place information can promote efficient outcomes that are not achievable under nationwide policies. Finding an instrument capable of reflecting these localized marginal cost levels is, of course, highly problematic.

Covering the Full Costs of a Road. That marginal cost pricing may lead to situations in which the revenues collected do not equal the total costs of a facility has long been recognized. The classic case in this regard is that of a bridge where average costs continue to fall as usage increases until a point of congestion is reached. Decreasing average costs are due to the large initial investment required for the bridge with relatively small maintenance costs attributable to additional traffic. After the point of congestion is reached, however, marginal costs (inclusive of the external congestion costs) rise rapidly, in which case full marginal cost pricing can yield total revenues that greatly exceed the total costs associated with operating the facility. The implication of this theoretical exercise is that one cannot expect efficient pricing of a public facility necessarily to yield revenues that just equal the costs of its provision.

For uncongested rural roads in most developing countries, the analytical model leads one to suspect that if marginal cost pricing was used; i.e., if each vehicle using the facility was charged an amount exactly equal to the full marginal maintenance and external costs associated with its use, total revenues raised would fall short of the total costs of providing the facility. This is because the total costs of a road include both variable and fixed maintenance costs. A marginal cost pricing rule would be sufficient to cover only the first of these.[11] Note, too, that the same logic leads one to expect that highly used roads on which congestion charges are imposed might yield revenues in excess of the total outlays necessary to maintain the facility.[12]

The objective of economic efficiency will not lead to the outcome where each and every road must pay for itself from user-based revenues. Indeed, marginal cost pricing throughout the road sector will not neces-

[11] Such a rule also ignores the initial investment costs of a road; once built, the marginal costs of an additional user (in the absence of congestion) include only the additional maintenance costs.

[12] Newbery (1989) demonstrates how congestion charges, if imposed in Britain, could yield revenues slightly in excess of total recurrent highway costs plus interest on total capital costs.

sarily lead to a balanced budget for roads. It is likely that uncongested rural roads will incur deficits while efficient pricing of congested urban roads will produce surpluses; together, the two may come closer to balancing the overall road budget (see Walters, 1968:83-86). If balanced road budgets constitute another financial objective, this argument suggests that comprehensive financing of an overall road system consisting of both rural and urban roads will more likely achieve success than a highly decentralized road financing scheme will.

Specific mechanisms capable of approximating marginal road-user costs are considered below; however, it is useful at this point to consider how, if at all, any shortfalls in revenues between efficient road-use charges and total costs of the road might be covered. In the classic literature on decreasing cost industries (natural monopolies), the use of "general revenues" is usually recommended. While there is no reason to dispute this normative prescription, it is more practical in fiscally stressed developing countries to determine whether certain revenue sources are theoretically preferred and would still achieve the objective of meeting the costs of road construction and maintenance.

One obvious source of such revenues could be the additional benefits generated from a road. As with any other capital infrastructure, if a road is economically efficient, it generates benefits in excess of its costs (where these costs include both variable and fixed maintenance costs). If the road is not generating such a surplus of benefits, no level of maintenance is justifiable. The task, therefore, is to craft resource mobilizing instruments capable of capturing the generated surplus from beneficiaries of economically efficient roads. Even with a portion of such surpluses taxed away, the beneficiaries of the road would enjoy positive net benefits (since the working assumption here is that the road is yielding benefits in excess of its total costs).

Walters (1968) demonstrates that under ideal market conditions, the benefits of a road that appear as lowered transport costs will be reflected in higher land rents; hence, he concludes that:

> It is clear that the 'best' tax to levy is one that easily extracts a revenue proportionate to the benefits received without changing land use. A tax on the rent of land is the obvious, and indeed classic, form of impost that performs these tasks. The land taxes will merely extract the surplus and will not affect allocations of resources (ibid., 139).

He goes on to note, however, that the tax must not be of the usual form of property tax that simply imposes a charge on total rents but instead imposes a charge on the *incremental* rents attributable to the road. While attempts have been made to levy such taxes to finance location-specific facilities in urban areas of some developing countries, they are difficult to administer and may prove to be politically hard to impose.[13]

Because of the political and administrative difficulties of an incremental land rent tax, Walters goes on to explore the implications of either a ton-mile tax (where the tax burden is related to the road mileage utilized, as in a gasoline tax) and a simple tonnage tax (such as an export duty). His theoretical analysis shows that the latter is superior to the former on several grounds. First, the tonnage tax is more efficient in that it restricts agricultural production much less than an equal yield ton-mile levy. Second, if revenue maximization is the objective, the tonnage tax can yield considerably greater revenues. Third, the tonnage tax is more consistent with the common views of equity. While a ton-mile tax will impose greater taxes on road users farther from the end-point of the road, Walters' analysis shows that, beyond some point, benefits from the road decline. Hence, benefits and tax costs are inversely related under a ton-mile tax, whereas they are directly related under the tonnage tax.

Two principal conclusions result from this review of the theoretical underpinnings of road maintenance finance. First, efficient road-use charges that reflect the incremental costs of using a road are unlikely to result in revenues sufficient to meet the full costs of the road. This is particularly the case for rural roads where no congestion occurs and where some main-

[13] See Doebele, Grimes, and Linn (1979) for a discussion of one successful use of such charges in Colombia.

tenance activities are invariant to road use. Second, the full costs of a road can be generated from the benefits that the road yields as long as the road investment is an economically efficient one, i.e., produces benefits in excess of the costs. A corollary of this latter conclusion is that taxes imposed on the incremental land rents generated from a road constitute an equitable and efficient method of financing. If such levies are impossible to impose on either administrative or political grounds, the practical issue then becomes finding adequate financing mechanisms that are positively related to road-use benefits.

Road Financing Mechanisms

In order to achieve efficiency, a road financing instrument should first reflect the differential marginal maintenance costs associated with road use. In this subsection, we begin by considering fiscal instruments that might be capable of capturing revenues in an efficient manner. We then turn to the additional problem of developing instruments that could be used to cover any additional shortfall of revenues that would arise if substantial economies of scale are present in road services. The discussion closes with a consideration of the financing issues associated with roads that are administratively under the control of local jurisdictions.

One might ask why it is of concern for user charges or use-based taxes to be set such that they approximate the additional maintenance costs of transport. Without such approximate equalities, economic inefficiencies will result. As long as there is a responsiveness of transport users to the price of transportation, i.e., the elasticity of demand is greater than zero (in absolute value terms), prices greater than marginal costs will result in a smaller quantity of transportation being consumed than is economically optimal. When congestion occurs, the prices paid by road users are less than the marginal costs and there is overconsumption of transport services. The review of road-user charges in Latin America by Churchill (1972:101-105) includes an estimation of the economic losses imposed by fuel taxes that do not reflect the marginal costs of differential variable maintenance costs across vehicle types and types of rural roads. He shows how a reduction in these taxes by 20 percent (which would reduce vehicle operating costs by approximately US$0.02 per km) would result in increased output of US$4 million for five countries—Guatamala, Honduras, El Salvador, Nicaragua, and Costa Rica. While the exact magnitudes of these estimates are not particularly relevant now nearly 20 years after the research, the economic argument still stands—excessive use-based taxes artificially restrict road use and, hence, the economic benefits from roads.

This is not to say that proper marginal cost pricing cannot yield considerable revenues (Newbery, 1989). It does imply, however, that concern solely for revenue generation can produce inefficiencies that lead to losses for the economy.

Factors Influencing Marginal Maintenance Costs. An ideal user-financing instrument would be continually altered to reflect the full marginal maintenance and external costs of each vehicle passing over a road; however, no such practical instrument is available. Indeed, due to the public nature of roads and the difficulty of excluding nonpayers, user charges that could be varied according to specific roads, types of vehicles, and seasons of the year are also infeasible. Instead, more general financing mechanisms, such as taxes and fees, must be implemented. The question arises as to whether or not any of these instruments are sufficiently sensitive to differential marginal maintenance costs to provide a reasonably efficient financing mechanism for roads.

In the search for such a mechanism, one must first determine the extent to which different types of vehicles create the need for road maintenance and then ascertain whether any fiscal instrument is capable of reflecting these differential costs. Unfortunately, the damage caused by an incremental user of a road varies so greatly by type of road and type of vehicle that it is probably impossible to tailor a financial instrument or instruments to capture these differences in an administratively feasible manner. The associated marginal maintenance costs vary tremendously across different road surfaces. For example, Walters (1968:181) reports that findings from Venezuela in the late 1950s indicated that additional maintenance costs associated with use of an earth road may be 50 times as great as those associated with a paved road and about three times as great as those of a gravel road. This would suggest that financing instruments should place considerably higher fees on vehicles passing over unpaved roads than over paved surfaces. Since vehicles are likely to travel over a variety of road surfaces, financing instruments are unlikely to be able to differentiate the relative distances traveled across each road type. Instead, the financing mechanisms may have to be tailored on the basis of relatively crude average traffic flows over different road surfaces.

While there probably is no financing mechanism capable of reflecting such great differences of marginal maintenance costs across different road surfaces, there are apparently sufficient differences in maintenance costs across vehicle types to structure differential fees that capture these differences. Much of the research here is contained in Paterson (1987). Automobiles obviously create considerably less damage to a road surface than trucks (except in the rather unlikely case of extremely strong road surfaces where the marginal maintenance costs for all use types is nearly zero). These differences suggest that heavier road-use charges be levied against larger vehicles than against automobiles.

Perhaps the greatest maintenance cost differential that arises is between properly loaded and overloaded vehicles. This problem is particularly pronounced in developing countries where enforcement mechanisms are weak and, due to resource constraints, roads are commonly not built to appropriate standards. Saccomanno and Halim (1983) argue that there may be instances in which it is economically efficient for developing countries to remove all regulations concerning weight limits on trucks other than load limits on bridges (since without such limits, bridges could fail and lead to loss of life and longer-term disabling of transport routes). The basis for this argument is that the societies of developing countries derive extremely large benefits from truck transport. While overloaded trucks may cause early deterioration of roads, the authors argue that the gains enjoyed by consumers and producers significantly exceed the additional costs imposed on the highway departments that such overloading causes. Although this argument could result in minimization of total costs of transportation (the private operating costs of the vehicles plus the costs of rehabilitating the road systems), it ignores the practical concern for raising sufficient revenues to meet the costs of building and maintaining roads.

For rural areas in at least some developing countries the problems of road maintenance are less related to motorized vehicles than to nonmotorized carts. Again, there can be significant differences in the marginal maintenance costs attributed to different types of vehicles. For example, Swaminathan and Lal (1979:15-16) report that a solid-wheeled cart is twice as damaging to an earth road surface than a heavy vehicle with pneumatic tires, and five times more damaging than a light vehicle with pneumatic tires. This would suggest that financing instruments that focus only on motorized vehicles will fail to achieve efficient outcomes.

While the focus here is on raising revenues capable of meeting maintenance costs, the significance of congestion cannot be ignored. Unlike maintenance costs, congestion costs are reasonably similar for different types of motorized vehicles; nonmotorized vehicles again may contribute significantly greater costs. Hence, efficient financing instruments should also be tailored to reflect these differentials.

Alternative Financing Instruments. A variety of road financing instruments is available, particularly for motorized vehicles.[14] One type of instrument indirectly imposes levies on vehicle usage by taxing inputs, such as fuel, tires, and lubricants. The advantage of these taxes is that they are related to the amount of vehicle use and therefore come closer to reflecting differential levels of imposed road maintenance costs. Furthermore, since heavier vehicles may use larger amounts of at least some inputs (such as fuel) for the same distance traveled, the levies can reflect weight-related maintenance cost differences. A downside to fuel charges is that the product may also be used for nonroad purposes, in which case nonroad users are discriminated against; a problem with taxes on tires and some spare parts is that they may discourage replacement of worn-out tires, brakes, lights, etc., and therefore contribute accidents that impose costs on others.

[14] For a review of alternative tax instruments applicable in cities of the developing world, see Linn (1979). Because of its emphasis on urban areas, the paper stresses congestion costs rather than maintenance costs.

Another type of levy on road use is registration and licensing fees. The principal advantage of such charges is that they can be tailored to reflect differential damage costs for different types of vehicles, for example, higher fees placed on heavy trucks than on automobiles. This instrument could also be used in rural areas to assess charges on nonmotorized vehicles that do significant damage to earth road surfaces; administering such licenses is, however, extremely difficult and costly. The principal disadvantage of fees is that they do not discriminate according to road usage. Two similar vehicles may be forced to pay the same annual registration charge even though one is used for many more vehicle miles in a year than the other.

A third type of financing instrument is on the original purchase or resale of a vehicle. While convenient to levy (at least at the central government level), again, such charges do not discriminate among different use patterns. Furthermore, since they are imposed only at the time of purchase or repurchase, different turnover rates will result in differential burdens that do not necessarily reflect different use-patterns.

Given this array of potential financing instruments and their relative advantages and disadvantages, is any one of these instruments or combination thereof likely to be optimal? The answer is likely to be heavily dependent upon the type of road network being used, the traffic patterns associated with that network, and the combination of congestion and maintenance costs the charges are to reflect. Furthermore, the set of efficient charges will be heavily dependent upon the overall structure of prices that hold in the economy since it is likely that, due to noncompetitive factors as well as other policy objectives, prices will be distorted. Obviously, these factors differ greatly among countries, and general, comprehensive conclusions are impossible to reach.

Perhaps the most extensive policy-oriented research made in this area is that conducted by Newbery et al. (1988) in Tunisia. Their wide-ranging analyses included investigation of road-use costs (including road congestion costs) and the effects throughout the economy of the implementation of taxes on different types of fuel as well as other road-use- and nonuse-related vehicle charges. Of particular importance in this investigation was concern for the substitution effects of taxes on specific fuels. Kerosene and diesel fuel are substitutes in at least some uses, while diesel fuel and gasoline can be substitutes for powering motorized vehicles. High taxes on gasoline encourage switching to diesel fuels while higher taxes on diesel fuel encourage adulteration of diesel with kerosene, which is commonly subsidized to promote its use as a home-use fuel by lower income families (and perhaps to discourage cutting of timber). As stated by Newbery et al. (1988:87-88), "This implies that domestic prices of diesel oil and kerosene should, as far as possible, be kept reasonably close to border prices, which limits the extent to which diesel oil can be used to recover road-use costs from the freight transport sector." The analysis also recognized that policymakers were concerned with the income and spatial distributional impacts of different types of freight-based charges. Of particular interest was the fact that the government wished to spread development benefits throughout the country, particularly in the low-income hinterlands, rather than have it concentrated around the cities. Vehicle-use related taxes add to production cost differentials between regions suggesting that greater spatial equity can be achieved only through subsidization of freight transport. The upshot of the analysis is that taxation of road use is an extremely complex topic, particularly when it is recognized that there are goals in addition to economic efficiency that are desirable. Furthermore, the goal of achieving multiple objectives suggests that multiple revenue instruments must be utilized.

Decentralized Road Provision. In many countries, road services are organized hierarchically. Higher levels of government are expected to provide primary and regional highways. Lower-level jurisdictions may be given the responsibility to finance arterial, farm-to-market and rural roads. While initial construction costs of such local roads may be covered by higher-level governments, maintenance is commonly the responsibility of lower-tier jurisdictions. Such arrangements create additional challenges to designing appropriate road financing mechanisms. Furthermore, these issues have not been examined extensively in the literature.

At least two specific difficulties arise in the case of locally provided roads. While it would still be desirable that the financing instruments used reflect marginal maintenance costs, the spatially limited nature of local jurisdictions, where interjurisdictional mobility is likely, makes it more difficult to find fiscal instruments that will achieve this objective and, simultaneously, be administrable. Second, because rural-dominated areas may not face any problems of congestion, economically efficient charges that reflect external costs, even if administrable, cannot be expected to yield adequate revenues to meet the full costs of road services; some supplemental revenues must be generated. On the other hand, the technologically simpler roads of rural areas of developing countries may make less traditional resource-mobilization techniques feasible.

The previous discussion suggested that, while not necessarily optimal, use- and nonuse-related vehicle taxes are reasonable instruments capable of capturing the full marginal costs of road services. Unfortunately, the same instruments are less likely to be optimal at the local level for at least two reasons, each of which is related to mobility. Since vehicles are unlikely to be restricted to a single jurisdiction, their purchases of inputs (or even their registration) will not necessarily occur in the same jurisdiction as the costs that they impose on the roads occur. Hence, even if administratively feasible, local vehicle input taxes and registration fees may not be highly correlated with local road usage. Second, while it might be desirable for differential user fees to be imposed across jurisdictions to reflect different local road networks, users might escape higher tax jurisdictions by purchasing inputs outside the jurisdictional boundaries. Related to this issue, in many developing countries there may be few outlets in some jurisdictions that sell vehicle-related inputs, e.g., petrol and tires, even though these rural-dominated localities have extensive road networks.

A more practical consideration regarding the difficulties of imposing local taxes on vehicle inputs is their administrative costs. Whereas a higher level of government may impose taxes on gasoline and tires at either the wholesale distributor, point of manufacture, or even at the point of import, local governments would have to impose such levies at the retail level thereby adding greatly to administrative costs. Similarly, taxes on the sale and/or resale of vehicles are probably most readily administered by the highest levels of government since it is the central government that oversees customs duties as well as records of vehicle ownership. Hence, the more traditional transport-based levies on vehicle ownership and usage are unlikely to be efficient or even feasible at the local level in most developing countries.

Furthermore, as noted above, even if efficient user charges could be imposed by rural local governments, efficient revenue instruments would be incapable of yielding sufficient revenues to meet the full costs of road construction and maintenance, since most of the roads controlled by such governments are likely to be uncongested, with much of their deterioration unrelated to use. Two possible alternatives remain to meet such costs. One is to mobilize resources locally, but in a manner that does not necessarily link the resources generated closely to the marginal costs of road maintenance. A second is to rely on higher levels of government to collect efficient road transport taxes and to distribute a portion of the resources to the localities for the purpose of road construction and maintenance.

One obvious choice of a local tax instrument in rural areas of developing countries, where the bulk of the road traffic is used to transport agricultural inputs and outputs, may be a tax on land rents. Where products are being supplied to a competitive market, such a levy can extract some portion of the additional benefits yielded from the road and its maintenance and will not result in a reallocation of resources. If, however, the road handles considerable through traffic, the land-based tax should not be relied upon to generate revenues sufficient to meet the full costs of road maintenance.

Walters (1968:197) notes that where farm-to-market roads are generally all of earthen surface, it might be possible to impose local market fees on produce. The presumption here is that the primary users of the local roads are market users who are deriving the benefits from the roads and are also imposing the additional costs of road maintenance. Obviously, such a tax is crude since it does not distinguish between the marginal costs of maintenance imposed by different modes of transport (which might range from motorized traffic to head-loads) and imposes equal costs regardless of the length of the trip. Nevertheless, given the administrative difficulties associated with land taxation, it is perhaps a reasonable alternative for a local levy.

Another local resource mobilization option that could be used for certain maintenance efforts on rural earth roads is voluntary contribution of labor or certain nonlabor inputs, such as small tractors and drags necessary for the road maintenance process. (Labor-intensive maintenance management techniques are discussed in the following section.) If road users are generally limited to those residing along the road, it may be feasible to design a system in which the amounts of resources mobilized are generally in proportion to the use of the road (or levels of benefits derived therefrom). The success of such efforts would depend on sufficient recognition of the benefits derived by each of the road users and minimization of free riding either through legal sanction or simply through moral persuasion. Rural roads in the United States were maintained in this manner up to several decades ago, and there may be many examples of such informal resource mobilization techniques currently in use on rural roads in the developing world. While such mechanisms are apparently not used extensively in developing countries (Beenhakker 1987), they do merit additional consideration.

The second possible source of revenue for local road construction and maintenance is the higher level of government, which, as noted before, does have adequate mechanisms available to mobilize considerable resources from the road transport sector. Indeed, it may well be the case that the total amounts earned from this sector exceed the amounts spent therein. One obvious reason for this "sectoral surplus" is that insufficient funds are being spent on road construction and maintenance. To the extent that the use of rural roads generates national government revenues (for example, through taxes on motor fuel and tires), it is economically efficient to transfer a portion of these revenues to the levels of government that are responsible for local road maintenance. A second important reason for considerably more revenues to be raised from transport-based taxes and fees than are spent in the road sector is that such taxes and fees can be much more easily collected in many developing countries than can taxes on personal incomes or sales. Vehicles, fuel, and other vehicle-related inputs can be taxed at the time they are imported or manufactured, making tax collection quite easy; this provides a strong incentive for national governments to tap these taxable resources at a level that exceeds the amounts being spent on road construction and maintenance. Reducing vehicle-related taxes and fees would either require imposition of other taxes on hard-to-tax sectors or would result in lowered overall levels of taxation, which in many fiscally stressed nations is not a viable policy alternative.

Several issues arise in conjunction with such resource transfers. First, designing an appropriate grant structure is difficult since it requires that the monies be distributed generally in proportion to the marginal road-use damage that the taxed vehicles cause. Perhaps allocation formulas based on road surface composition and road usage could be designed to achieve a reasonably efficient distribution. Second, such a distribution is likely to result in a spatial reallocation of monies from urban to rural areas, since efficient user charges can result in surpluses in more congested urban areas and deficits in uncongested rural locations. This could create political opposition from those representing urban interests. Third, a practical problem arises when the higher level of government must rely heavily on the transport-based taxes to provide revenues available for other general expenditures such as defense, education, and health. Ministries of Finance may be unwilling to relinquish these badly needed revenues. Finally, the question remains as to whether or not the funds transferred to local governments would, in fact, result in road maintenance. These last two issues are closely related to the more general problem of budgeting for road maintenance, to which we now turn.

Road Maintenance Budgeting

Whether or not revenues potentially available for road maintenance are mobilized in an economically efficient and equitable manner, maintenance activities will not be undertaken unless the budgetary process allocates the available funds to these activities.[15] Compared with the issues associated with road main-

[15] Although budgetary allocations are necessary for maintenance to occur, they are not sufficient. The allocated funds must be disbursed and actually spent for maintenance purposes.

tenance activities discussed in Section II or even the finance issues discussed above in this section, issues associated with road maintenance budgeting are probably much less understood and are certainly much less studied. Of particular interest here are questions as to how much money ought to be put into road maintenance and issues concerning the possible roles of earmarking some revenues for that purpose.

Normative Budgeting Practices. It is not difficult to state how a rational budgeting process should allocate funds to road maintenance. In the ideal situation, a decision-maker would have some idea of the costs and benefits of alternative budgetary allocation strategies. This means that for each stretch of existing road and for all potential roads, the decision-maker would know how much various types of road maintenance (either routine or periodic), rehabilitation, and construction would cost and the economic returns that each of these activities would yield. Furthermore, in the ideal situation where there are also other competing activities, such as providing for sectors other than transport (e.g., agriculture, health, education, etc.), the costs and benefits of each would also be known. Where there is a budgetary constraint to be met, maximization of total benefits can be achieved by arraying all of these alternatives in accordance with their benefit-cost ratios and undertaking all of those activities (where the ratios are greater than one) until the budget available has been exhausted.[16]

This ideal approach will not necessarily mean that all road maintenance activities can be carried out in a single year. If the budgetary constraint is such that only some portion of the possible maintenance activities can be afforded, only those activities with the largest benefit-to-cost ratios should be undertaken. This may mean that some routine or even some periodic maintenance activities will have to be deferred or undertaken at less than optimal levels. For example, while the traffic levels and benefits generated may indicate that two bladings of an earth road are optimal, the lack of available funding together with higher returns on other activities may mean that only a single blading of the road is justified unless additional revenues can be generated. Furthermore, the model may reveal that certain roads, for which benefits do not exceed the costs of upkeep, should be abandoned.[17]

Actual Budgeting Practices. Obviously, actual budgetary allocations for road maintenance and repair fall far short of this ideal process.[18] While the previously noted lack of revenues available for road maintenance is probably a major contributor to the lack of funding, the budgetary processes used may also contribute to the problem. The ideal budgetary model described above is seldom, if ever, used. In part this may be due to lack of information. Governments responsible for road maintenance often do not even have full inventories of the roads for which they are responsible; without such basic information it is unlikely that rational decision-making can occur. Furthermore, while we have attempted to provide some information on the costs and benefits of road maintenance, relatively little information is available and this is generally limited to only a few countries in which extensive research activities have occurred over some period of time.[19]

[16] This is simply a restatement of the well-known maximization strategy discussed in conjunction with the use of cost-benefit analysis. See, for example, Gramlich (1981).

[17] For a schematic illustration of such a process, see Edmonds (1989:13).

[18] Furthermore, this is as true in high income countries such as the United States as it is in the developing world. A recent examination of budgetary allocations to maintenance of streets and highways in 40 cities of the United States during 1978-84 showed that many were putting far less money into this activity than was estimated to be the depreciation on these capital facilities (Peterson: 1986). Pavement replacement rates (especially resurfacing of existing hard surface streets) averaged only 48 to 63 percent during the seven years. Furthermore, individual cities were found to be replacing streets at a significantly lower rate. For example, Chicago was found to have replaced only 1 percent of what should have been replaced during the years 1978-80, on the basis of the overall city street network and design principals; Detroit and Oakland were not much better at 6 and 7 percent, respectively. On the other hand, Cincinnati's replacement rate was 159 percent.

[19] The long-term nature of road deterioration and the complexities of the deterioration process also contribute to this lack of information, since it is difficult to factor out the exact causes of the deterioration, e.g., vehicle use, weather, inadequate road construction, and the relative contributions of each.

This lack of information is not limited to developing countries. In a report to its 26th World Road Congress, the Economic and Finance Committee of the Permanent International Association of Road Congresses (1979:33) noted that "In Great Britain, at least, there is as yet insufficient data available in the way of unit cost information for maintenance operations" and "We know relatively little about the benefits of maintenance" (emphasis in the original). Furthermore, experiments necessary to obtain such information are expensive. Newbery (1987:7) reports that the most extensive study of highway deterioration in the United States would cost over US$300 million in 1980 prices to replicate. Given the budgetary constraints faced by governments throughout the world, it is impractical to expect that full information on the costs and benefits of maintenance will be available in the near future.

Even with imperfect information, the budgetary process used by public sector authorities may itself contribute to suboptimal or even highly uneconomic results. When road construction and maintenance are only a portion of the activities over which budget-makers have responsibility, road maintenance may get very short shrift, for various reasons. Even when the costs and benefits of road maintenance are known with certainty, competing needs may take greater precedence. For example, if the choice is between allocating funds to road maintenance or to education, budget-makers may feel that education spending is a higher priority, in which case road maintenance will necessarily be deferred.

When a lump sum amount is made available for the road sector (whether it be defined at the national level to include all roads and highways or only national highways, or at the local level to include only those roads for which the local authority has responsibility), the budgetary process again may result in suboptimal allocations to routine and periodic maintenance. As both this paper and *Institutional Incentives and Rural Infrastructure Sustainability* have stressed, road maintenance efforts (especially those of the routine variety) are likely to produce benefits only over a longer period of time. Hence, when faced with the decision of how to allocate a limited amount of funds among routine, periodic, and emergency maintenance as well as more major activities such as road rehabilitation, reconstruction, or new construction, a road authority may view road construction or improvements as yielding higher payoffs when costs and benefits are discounted to the present. It may be extremely difficult to ensure that some portion of the total funds is set aside exclusively for routine maintenance when there are many miles of roads that have deteriorated so badly that only rehabilitation will return them to an economically useful state.

Two additional factors can exacerbate this situation. One is simply the politics of the budgeting process. The normative model assumes a fully economically rational system of budgeting, yet choices in political environment are obviously affected by factors other than costs and benefits (even if fully and accurately estimated). Uses of funds for purposes other than road maintenance may be politically more popular; similarly, routine maintenance may yield less popular reactions among the voting public than reconstruction or even more periodic maintenance activities. Overcoming these political barriers to budgetary allocation for maintenance requires an enlightened public or sufficiently strong interest groups. When the decision-making body is closer to the people, such as when those using the roadway are active participants in the budget-making process, increased allocations for maintenance may result. However, this is not a topic that has been sufficiently researched in either the developing or developed world.

A second aspect of budget-making that cannot be ignored is the relative price of new construction and maintenance. Where new construction is highly subsidized, e.g., when donors make funds for new construction available to a developing country at highly subsidized prices or where a local government is provided with cost-sharing grants to build new roads, the budget-making body is likely to prefer these subsidized activities to nonsubsidized maintenance activities.[20] If only a limited amount of funding is available either to match the external grants or to be used for maintenance, the relatively lower price of the former can be found to yield the largest net benefit to the recipient body. Shortsighted budget-making in such a situation (especially in a political environment in which the future costs of subsequent maintenance may be irrelevant to current office-holders) can lead to suboptimal spending on current maintenance.[21]

Earmarking. The problems of ensuring adequate maintenance spending within a budgetary process are not new, nor are they unique to roads. Two proposals to increase allocations to road maintenance include the use of earmarked road funds and changes in grant allocation mechanisms. While earmarking might not result in a significantly greater proportion of total road spending on maintenance (since maintenance would still be in competition with construction and reconstruction as alternative uses of the funds), it might result in more certainty that funds would be available for maintenance. In essence, earmarking is expected to increase the size of the total budget portion allocated to roads; with a larger and more certain sectoral allocation, the totals spent on maintenance might be expected to increase.

Institutional Incentives and Rural Infrastructure Sustainability briefly reviewed the overall argument regarding earmarking. Transportation is the one area within the public sector activities most conducive to earmarking, since transport-related inputs such as fuel and tires can be tapped quite easily. Earmarking transport-based taxes is quite common in the United States. For example, 48 of the 50 states levying motor fuel taxes earmarked at least some portion of the tax proceeds (Gold, Erickson, and Kissell, 1987:11). In fact, in many developing countries where administrative constraints preclude broad-based taxes such as taxes on incomes, the transport sector is especially attractive for taxation. The lack of other good tax handles will limit the extent to which the funds raised from transportation should be reserved for the transport sector. This point is at the heart of the efficiency argument against earmarking. By restricting the use of mobilized revenues to the earmarked purpose, the economy could be foregoing benefits attainable from other uses of the funds.

The paucity of funds spent on maintenance together with the potential of earmarking to make considerably greater amounts of money available in developing countries justifies a more in-depth review of the arguments favoring this budgetary device. Probably the most complete recent restatement of the arguments is that by Teja (1988). He reviews the public economics theories of Wicksell, Lindahl, and Johansen that can be used to support earmarking on grounds that, if consumers' preferences are revealed, earmarked taxes are essentially benefit levies and can lead to a situation in which all taxpayers are better off than they would be if general fund financing is used. The key assumption here is, of course, that preferences are revealed.

Teja goes on to indicate how public choice theory also supports the earmarking concept. Earmarking provides a more direct link between the availability of a public service and its tax price. Increasing the quantity of any particular public service will result in a higher earmarked tax bill whereas, with a fixed total budget, increasing a service financed from a general fund will result in lesser amounts of other general fund-financed services. Earmarking makes the opportunity cost of any public service much clearer to the voters.

Other arguments supporting earmarking include the bureaucratic-based theory often attributed to Niskanen (1971), in which bureaucrats may interfere with the public-choice process. Teja hypothesizes that bureaucrats may see spending on capital maintenance as less prestigious than new capital spending; by tying revenues to the maintenance activity, sufficient resources will be made available for maintenance to occur. Similarly, he notes that the unstable revenues characterizing the resource structure of many developing countries can result in revenue shortfalls that threaten the longer-term sustenance of capital projects as general fund revenues are siphoned off for

[20] Such behavior is not limited to roads nor to developing countries. For an interesting demonstration of how U.S. federal government grant policies adversely affect maintenance of intercity buses, see Cromwell (1989).

[21] For a discussion of the longer-term recurrent costs implications of capital spending see USAID (1982).

other purposes. Earmarking can help overcome this phenomenon. Of course, the revenue sources selected for earmarking should not be subject to significant instability, as this would lead to even greater problems for capital sustenance than if maintenance were financed from the general fund.

Teja recounts the principal arguments against earmarking presented by Deran (1965). The basis of these counterarguments is that the budget process allows budget-makers to adjust both total revenues and the uses thereof on an annual basis so as to approximate the socially optimal allocation of resources. Earmarking is seen to tie the hands of the budget-makers and is expected to be unchanged even if circumstances change. Since there is some evidence that much budget-making is done on an incremental basis, one wonders if the presumed flexibility of general fund financing is any greater than that which would occur under earmarking.[22]

Experiences in earmarking for purposes of road financing in developing countries have not been uniformly positive. Harral and Faiz (1988:28) indicate that while earmarking of transport-based taxes has been attempted in several countries, "A frequent problem is that money earmarked for the road fund does not find its way there or is used inefficiently or for purposes other than maintenance." While these results suggest that no budgetary mechanism can fully ensure an adequate funding level for road maintenance, the fact that governments have overridden the earmarking indicates a weakness in one of the primary arguments against it—namely that earmarking puts governments into totally inflexible budgetary positions.

Local Government Budgeting. In the case of local governments, earmarking of local revenues for road maintenance is even more problematic given the paucity of good local resource instruments that are tied to road use. As noted earlier in this section, gasoline taxes are unlikely to be good candidates for *local* taxation and, except for quite large areas, vehicle registration fees are unlikely to result in significant revenues for rural localities. The one exception here could be land-based taxes; however, if these revenues constitute the principal local revenue source available for all uses, earmarking all such revenues could be highly inefficient.

As previously suggested, intergovernmental grants provide for significant funding of local road maintenance. Intergovernmental grant revenues face two different budget processes between initial revenue collection and final allocation to a particular purpose. First, national budget-makers must determine the amounts to be allocated among recipient governments; second, local governments must allocate grant receipts. Whether grant monies are ultimately made available for the maintenance of local roads will therefore depend on the outcomes of these two processes.[23] If statutorily predetermined portions of certain central government tax revenues are shared with local governments (really another form of earmarking), there should be a greater likelihood that the revenues will actually be transferred to local governments than when the amounts to be made available to local governments are determined on an essentially *ad hoc* basis as part of the annual budget process.[24] Second, the grant mechanisms can be designed to encourage or mandate that the grant monies be spent for maintenance purposes. Unfortunately, while such mandates can be imposed, they are often extremely difficult to enforce. This is partly due to the difficulty in defining what activities constitute maintenance and partly due to the lack of effective fiscal auditing (Schroeder, 1988).

The review of maintenance finance and budgeting in this section has suggested that there is no easy solution to ensure that adequate funding will be made available for road maintenance at either the central or local levels of government in developing countries. There are some areas in which additional research is obviously needed. One problem is that it is hard to find truly successful instances of road maintenance finance from which lessons might be learned. Until

[22] See Wildavsky (1979) for discussions of the incremental theory of budgeting.

[23] For a review of the uses of intergovernmental grants in developing countries see Schroeder (1988).

[24] Schroeder (1988) notes, however, that tying government grants to national revenue collections has been subverted by higher-level governments when faced with overall fiscal difficulties.

such successes are located, experimental approaches based on generally accepted theoretical principals must be undertaken. Furthermore, the availability of funds alone is unlikely to ensure that adequate road maintenance will be forthcoming. Management practices must also be adequate to lead to success.

Management of Road Maintenance

DECISIONS concerning the use of resources made available for road maintenance may be as important and as difficult as the task of raising the funds. As has been stressed in two recent reviews of road maintenance issues throughout the developing world, institutional and management issues are at the heart of road maintenance failures. Robinson (1988: 18) states that "Although there are still some technical problems to be solved in connection with road maintenance, most problems that exist are institutional or managerial in origin, rather than technical." In a similar vein, Harral and Faiz (1988:2) note that, while technical, financial, and institutional issues are all important to the success of slowing the deterioration of roads in developing countries, "[O]f these, the institutional requirements are the most pressing."

While management and institutional issues affect nearly all roads in the developing world, they appear to be especially pronounced in the case of low-volume rural roads. Such roads serve a relatively small number of users far from the capital city, suggesting that decentralized institutions with emphasis on local participation have advantages over the more traditional, highly centralized approaches to road maintenance management commonly found in many developing countries. The first portion of this section therefore focuses on the role of decentralization in rural road development and maintenance.

In general, the construction standards for low-volume roads serving localized rural populations are much lower than those for major highways and arterial roads. As a result, highly labor-intensive construction and maintenance techniques are feasible for such activities. The second portion of this section is concerned with the choice of input combinations to be used to carry out road maintenance.

Finally, regardless of whether or not decentralized, labor-intensive techniques are utilized to produce road maintenance, an issue remains concerning how road maintenance activities are to be implemented. With the increased interest in reliance on the private sector to *produce* publicly provided services, it is useful to review experiences with maintenance contracting versus the more traditional methods of producing rural road maintenance. Thus, this section concludes by considering some of the primary issues related to contracting.

Decentralized Road Maintenance Decision-Making

Because of the nature of road services discussed in Section I, it is highly likely that nearly all types of roads will be provided by the public sector through bureaucratic organizations. An important issue that then arises is the form of these organizations and the incentives found in these various forms. Ideally, the organizations respond to the needs and desires of those using the road services; however, often in developing countries there are few effective mechanisms for linking users' needs to road development activities. Instead, the linkages between the bureaucracies overseeing roads and individual politicians, road contractors, and perhaps the donor community dominate what occurs in the sector. Furthermore, the politics within a particular bureaucracy also may significantly affect outcomes by shaping the incentives of its bureaucrats.

One important issue that can affect the degree of attention to rural road construction and maintenance is the breadth of control exercised by road agencies. Various organizational schemes are used in different countries. For example, there may be a single, road transport bureaucracy with control over all roads, ranging from minor, seldom-traveled local roads serving only a few persons to national highways. Or there may be independent organizations responsible for different types of roads; for example, a national road agency may oversee only major national and regional highways, with independent bureau(s) charged with managing other portions of the overall road network. While reliance on only a single agency can yield some economies of scale and can increase the amount of coordination in road building and maintenance efforts throughout the road network, there are important potential disadvantages to such an organizational design. The single agency retains a monopolistic position in road works. Without any competition, the monolithic agency is likely to focus its attention on these activities that lead to the greatest payoffs to the bureau in terms of its budget and prestige. Since national highways are technically more complex and more costly to build, it is likely that the single agency will focus its efforts on the national highway network rather than on the complementary secondary and tertiary rural roads. Although we are not aware of any systematic testing of this possibility, it might be anticipated that rural roads will get greater attention in an environment in which independent agencies are responsible for different portions of the overall road network.

Even when one bureaucratic agency is assigned responsibility for rural roads, there remains the question of the appropriate degree of decentralization within that agency. From their evaluation of USAID-funded rural roads, Anderson and Vandervoort (1982:28) concluded that:

> Involvement of local people in selection, construction, and maintenance of roads had several advantages. It laid the basis for road maintenance. Communities also found themselves better able to obtain more government services by forcing development programs to be more responsive to their needs. Local people began building more constructive relationships with higher levels of government and organized more effectively to protect their interests.

Although, as Tendler (1979:58-59) notes, popular participation is not a necessary result of decentralized approaches to road management, decentralization should improve the likelihood of local involvement. Furthermore, evidence suggests that decentralization can improve the longer-term sustainability of roads. Again, quoting from Anderson and Vandervoort (1982:11), "Decentralization of the rural road construction process or the active involvement of local governments and communities was an essential ingredient of successful institutionalization."

The relative benefits of decentralized over centralized road management systems are partly due to the constraints and incentives faced in highly centralized systems. When both construction and maintenance operations are managed by the same centralized agency, conflicts arise over the priorities assigned to each of these tasks. In most cases, construction wins out over maintenance, since the former attracts greater political support and is by far the more glamorous activity, as it requires greater levels of engineering expertise (National Research Council, 1979:3). In addition, the road agency is likely to be already overextended with respect to management resources. Extending maintenance to rural roads may be beyond the capabilities of such agencies.

Even when a centralized agency has the ultimate responsibility for rural road services, it is generally recognized that authority and responsibility for maintenance should be delegated to the lowest levels possible. Robinson (1988:7) notes that "this should result in a much more efficient organization and will reduce considerably duplication of work by senior staff." Unfortunately, experience with decentralization has not always shown such efficiencies to arise. For example, Cook et al. (1985:28) concluded that sudden decentralization of the Secondary Roads Maintenance Service (SERS) in Upper Volta led to efficiency losses. Similarly, the World Bank found that decentralization in Kenya and Honduras apparently led to excessive employment of permanent workers at the local level (Harrall and Faiz, 1988:19). Whether this should be attributed exclusively to decentralization of decision-making, however, is not certain since employment levels may be influenced considerably more by the methods of implementing road maintenance, e.g., contracting versus force account (see **Methods Used to Supply Road Maintenance** discussion later in this section).

Beenhakker (1987:168-172) notes ways in which decentralized management can gain the most from local participation in the planning, construction, and maintenance of rural roads. Among the steps he recommends are: an emphasis on employing local labor, including hiring local people as paraprofessionals who can improve the flow in communication between agency staff and local beneficiary groups; decentralizing procurement to as low a level of government possible; and maximizing the use of local materials and road-building technologies.[25] Again, the aim in such organizational approaches should be to provide an optimal blend of the beneficiaries' local time and place information with the technical expertise available at higher levels.

One issue that has not received much emphasis in the literature on decentralized road management is the most effective organizational design for maintenance activities. Beenhakker (1987:326-330) suggests that a typical maintenance organization should include: a headquarters unit; regional, district, or subdistrict units; field work force units; and maintenance equipment units. However, polycentric organizational units, with some functions decentralized to the lowest levels (such as the village), others handled at higher levels (such as subdistrict-level), and still others the responsibility of district or regional levels, may be the most effective. The varied nature of the maintenance activities discussed in Section II also indicates the potential effectiveness of polycentric approaches to maintenance. Such effectiveness, however, will have to be determined from experimental efforts.

One aspect of the most effective approach to organizational design is the degree to which labor and capital are emphasized in various phases of the production process. Capital-intensive processes generally lend themselves to more centralized management, whereas labor-intensive techniques may be most effectively implemented via more decentralized management. It is to this choice of production techniques that we now turn.

Production Techniques

For most production processes, outputs can be produced using different combinations of various inputs. Efficient production depends on both the technical efficiency of different inputs and the prices of these inputs. While techniques that rely relatively heavily on labor inputs may be less productive than more capital-intensive techniques, labor-intensive production can be more efficient if the price of labor is sufficiently below that of capital.

Road construction and maintenance provide good examples of this concept. Section II reviewed the technical tasks involved in carrying out road maintenance. Among the routine maintenance tasks specified in Section II is cutting vegetation from the shoulders and the ditches of a road. Obviously, this task can be performed either with a machine (e.g., a tractor and a mower) and an operator or by a laborer using a simple tool (a shear or scythe). With the former technique one operator may be capable of cutting considerably more area during a single day of work than an individual using shears; however, the capital-intensive technique is also likely to be considerably more expensive since it requires a skilled operator, greater capital investment, and greater operating costs. When the price of unskilled labor is sufficiently low relative to more capital-intensive inputs, economic theory predicts that the labor-intensive approach would be the more efficient despite its lower productivity.

In a study of labor-capital substitution in civil works projects, the World Bank concluded that:

> In countries with minimum wage levels up to U.S. $2.00 per day, suitable types of civil works should be executed by labour-intensive work methods, unless there are specific reasons against such a concept (e.g., due to the non-

[25] The use of paraprofessionals to improve flow of information is emphasized in Esman (1983).

> availability of the labor force in the project area). Where the minimum wage ranges between \$2.00 and \$4.00 per day, the use of unskilled labour should be conscientiously considered and with minimum wages slightly above \$4.00 per day, the appropriate mix of labour and equipment may still tend towards labour-intensive use under certain conditions (Project Completion Report: 1986, as quoted in Hagen, 1989:II-3).

Hagan goes on to note that since capital equipment costs have increased since that report was written and since local currencies have generally been devalued, the case for labor-intensive methods is even stronger.

In fact, there are several reasons that labor-intensive road construction and maintenance make sense in many developing countries. Obviously, high rates of unemployment and underemployment act to keep wages, especially those for unskilled labor, low. In addition, public policy objectives of lowering unemployment rates make labor-intensive approaches to road maintenance even more attractive. This is particularly the case in rural areas where labor-intensive techniques can achieve the dual objective of lowering unemployment and supplementing the level of income in the area. Second, the nature of many of the activities associated with rural road maintenance, especially those applicable to earth roads, is technologically quite simple. This means that the relative productivity of more capital-intensive approaches to maintenance efforts is lessened. For example, Roberts and Robinson (1983: 351) note that labor-intensive approaches are especially effective for cleaning and making minor repairs to culverts and bridges, repairing structures, patching or local sealing of bituminous surfaces, refilling unpaved surfaces (including shoulders), repairing slopes, and manufacturing, repairing, and replacing traffic signs. On the other hand, certain other tasks including compacting soil, grading unpaved surfaces, dragging unpaved surfaces, and stockpiling and resurfacing gravel are most effective using equipment-based methods. The issue of labor-based compaction is particularly important. As is noted in the handbook, *Labor-Based Construction and Maintenance of Low-Volume Roads* (p. 19), "There is clear evidence that compaction is one area of low-volume road construction where labor-based alternatives have trouble competing, both in terms of productivity and quality." This is especially the case where the earth used for construction contains large proportions of organic materials, as is true in Bangladesh (see Associates in Rural Development, 1989). Nevertheless, even in these instances, relatively more labor may be used in the process than might be in higher income countries.

Capital-intensive approaches using equipment-based strategies present some unique difficulties in developing countries. Most road construction and maintenance machines such as bulldozers must be imported, thereby requiring the expenditures of scarce foreign exchange. This, in turn, further raises the opportunity costs of capital-intensive approaches. In addition to the higher capital price of machinery, the shortage of skilled operators and mechanics further drive up wages of these inputs and, hence, the costs of using capital equipment in many developing countries.

Finally, while capital equipment may be more productive than labor-intensive approaches, this is the case only if the equipment is being utilized. For a variety of reasons, road equipment utilization rates in developing countries are extremely low. A study of equipment in Pakistan for the Indus superhighway project found equipment being used an average of only 1,000 hours per year compared with a standard of 2,000 hours per year in industrialized countries (National Research Council, 1981:2). Uniformly poor utilization rates were also found in a World Bank analysis of 43 countries (Harral, Fossberg, and Watanatada, (1977). There are probably several reasons why rates of utilization, and therefore equipment productivity levels, are low in developing countries. Because of the previously mentioned lack of foreign exchange, there is often a shortage of spare parts; the lack of skilled operators and mechanics can cause an increase in equipment breakdowns; and poor management techniques may lower the effectiveness of both the equipment and its maintenance.

Experience is slowly being gained concerning the effective use of labor-intensive approaches to road construction and maintenance. The International Labour Organization (ILO) has been especially active in compiling information on the applicability of labor-intensive approaches to road maintenance and construction (see, for example, ILO, 1979 and 1982).

Likewise, the Transportation Research Board of the National Academy of Sciences has actively supported research on maintenance techniques particularly appropriate for developing countries including publishing a handbook intended for policymakers, planners, and engineers that gives an easy-to-read overview of labor-intensive management issues (see National Research Council, 1981). Beenhakker's (1988) recent book contains a wealth of information and references concerning appropriate methods to be used in such approaches.

One experiment regarding the technical efficacy of labor-intensive maintenance of road surfaces was carried out in Kenya (Jones, 1984). Sections of earth roads were chosen randomly, with labor crews assigned the task of filling potholes and ruts following well defined and technologically proper procedures that included compaction. Road surface roughness measures were taken both before and immediately after the surfaces had been treated. This procedure was repeated approximately 60 days later, and again 120 days later, with measures of road roughness made prior to and immediately after treatment. The experiment demonstrated that such labor-intensive procedures were capable of significantly reducing road roughness. Furthermore, the experiment included monitoring the condition of the originally filled potholes (since if the procedures did not work, the same sections of the road would quickly revert to their original pothole-laden states). Jones (1984:18) notes that "Subsequent assessments of the road at the time of the repeated maintenance activity showed no further deterioration at these points. Any changes in roughness were therefore due to deterioration elsewhere on the road." While these results indicate the potential effectiveness of labor-based maintenance of rural roads surfaces, Jones also recognized that the degree of supervision in these test cases was high. Whether similar positive results would be obtained for extensive road networks would depend upon adequate supervision and inspection.

Cost analyses of labor-based maintenance strategies have shown they fare well when compared with equipment-intensive approaches. For example, a study by the Ministry of Public Works, Transport, and Urban Development of Upper Volta (now Burkina Faso) reported that average costs of manual maintenance procedures were significantly below that of mechanized approaches. The labor-intensive approaches averaged only franc CFA 46,000/km whereas the capital-intensive approaches were more than 20 times more expensive at franc CFA 1.2 million/km (Republic of Upper Volta, 1977).

Thus, while experience shows that labor-intensive maintenance techniques for rural roads can be successful technically and economically, it is not without problems. Several major factors are important to its success. First, while the bulk of the labor input may consist of unskilled laborers, skilled management is crucial to the success of labor intensive approaches. A pilot project in Botswana determined that there should be a trained leader for every work gang of up to 25 laborers, with a trained supervisor overseeing from four to six gangs (Hagan, 1989:II-5). Robinson (1988:9) noted that the quality and productivity of labor-based work is highly dependent on the quality of supervision, and supervisors need to be specially trained to acquire the skills needed to supervise large labor forces. Hence, labor-intensive techniques may themselves require investment to implement, i.e., investment in proper management techniques. Second, it is important that labor-intensive technology be implemented or at least planned at the time a road project is being designed since the effectiveness of road maintenance can depend on the nature of the roadway constructed. For example, "V"-shaped ditches are difficult to clean using labor-intensive methods (Beenhakker, 1987:313). Third, Cook et al. (1985:9) note that labor-intensive techniques are likely to require considerably more detailed planning than capital-intensive projects, since ultimate success will depend on such factors as supervisor and labor recruitment, training, allocation, scheduling, and payment procedures. Capital-intensive approaches, which involve fewer actors and simpler payment mechanisms, require less extensive operational overhead.

This list of considerations helps explain why, in spite of the seemingly obvious hypothetical appeal of labor-intensive techniques for developing countries and the successes obtained from experiments on the effectiveness of such methods, there are important institutional constraints to their implementation. Anderson and Vandervoort (1982:9) concluded that, at least for rural road construction, the incentives both within USAID and within host country institutions often resulted in a lack of implementation of labor-intensive techniques even though such methods had been originally planned. They note, however, that "where implemented, labor-based construction was a success."

Their findings regarding host country and donor bias towards equipment-based road construction methods were in accord with the arguments presented by Tendler (1979). She recognized that donor personnel overseeing road projects found their tasks simplified by capital-intensive techniques and that decision-makers within host countries, particularly those associated with centralized road departments, were also much more comfortable with equipment-based techniques (in part, because of past efforts on the part of donors who had previously encouraged such equipment-based approaches). Furthermore, it is often the case that local engineers have been trained (perhaps under the sponsorship of donors) in Western-oriented schools where the most modern technology is stressed. Such individuals may be hesitant in supporting the less advanced labor-intensive approaches to road construction and maintenance (National Research Council, 1981:2).

In summary, labor-intensive approaches to rural road construction and maintenance have considerable appeal in developing countries. Furthermore, they are particularly conducive to decentralized institutional structures that stress local participation. The management burden with such techniques is great, however, and successful implementation requires overcoming the significant built-in incentives favoring capital-intensive approaches that decision-makers face in both donor and recipient organizations. The extent of the management burden can be significantly affected by the methods used to provide the production of road maintenance. We now consider the range of these methods.

Methods Used to Supply Road Maintenance

Whether centralized or decentralized, labor- or capital-intensive, production of road maintenance is not necessarily the appropriate task for the public sector. While the nature of the service is such that the private sector is unlikely to *provide*, i.e., plan and finance road development and maintenance, the activities necessary for the *production* of roads and their maintenance can be carried out by private suppliers. Here we review the available alternatives and briefly discuss some experimental approaches involving the use of contractors to supply the full array of road maintenance activities.

Traditionally, governments have attempted to carry out the bulk of all maintenance tasks directly, commonly called the *force account* approach to maintenance. Under this technique, the implementing government directly employs labor (either as permanent staff or as temporary hires) and uses this labor along with the government's maintenance equipment to carry out maintenance activities (Harral, et al., 1986:1). Several factors have contributed to the frequent use of force accounts. First, the bias toward equipment-based technology common in many developing countries created a situation in which most contractors could not afford the necessary maintenance equipment. Second, it was often felt that alternative modes of production such as contracting would lead to a lowering of maintenance standards.

These views have changed dramatically in recent years with more and more governments attempting to use contracting as the maintenance production modality (Jorgensen and Whitman, 1984:139). The most important reason for this change has been the realization that under force accounts there are few built-in incentives for efficient production. Unlike contractors, who actively compete for the right to carry out maintenance, force-account employees face no competition and therefore have little incentive to improve efficiency.

Contracting for maintenance can, theoretically, have additional advantages. For example, with contractors concentrating on maintenance implementation, road departments can focus exclusively on planning and monitoring maintenance; likewise, private contractors may have greater flexibility in responding to seasonal fluctuations in the demand for maintenance than public bureaucracies. Harral et al. (1986:44) note, as well, that where maintenance has been a largely ignored activity, contractors can form an effective lobby for increased or continued funding of routine maintenance activities.

This is not to imply that contracting techniques have no potential disadvantages. By its very nature, it is extremely difficult to plan for emergency maintenance; therefore, it may still be necessary for the road authorities to retain some maintenance capabilities in order to respond quickly to emergency needs. Likewise, if contracts are to be monitored, they must be well specified. This requires considerable input on the part of the contracting agency, especially when specifying particular tasks that must be performed, such as repainting specific signs, filling particular potholes, etc. The costs of administering (planning, writing, and monitoring) such contracts may be as great as directly overseeing the process. Furthermore, a contract can reduce flexibility on the part of the maintenance producer since the legal consequences of not following the contract to the letter may lead to an inappropriate response to the maintenance task being faced.

Contracting may simply be infeasible in certain environments, and it takes time for an adequate private contracting sector to be developed. Harral and Faiz (1988: 20) suggest that trial introductions of small, technologically simple contracts for routine maintenance be used to help establish a contracting industry while keeping the risks of failure small. They recognize that successful contracting schemes require "close coordination between the government and contractors in defining the planning of work."

Even when there is an apparent supply of adequate contractors, the efficiency gains from contracting will occur only if there is real competition among those vying for the right to conduct the maintenance activity. Collusion is particularly problematic at lower levels of government, where local elites or other powerful groups can exclude others from participating in the process. An interesting recent case analysis of rural road contractors in Bangladesh revealed at least three different methods by which contractors colluded on contracts (Loft, 1989:23). Under a seasonal cartel, the colluders rigged their bids on tender offers so as to share nearly equally the total construction activity to be carried out during a season. *Ad hoc* cartels are also sometimes formed for a single tender offer, with payoffs given to the predetermined losers. Loft also found that in some instances bidders prearranged to bid exactly the same amounts on a contract under the expectation that the public agency would randomly choose the winning bidder. Detecting the last of these types of collusion strategies would be quite easy; however, the situation is complicated by the fact that there is often a close relationship between contractors and the public personnel overseeing the contracting process. For this reason, the administering agency seldom attempts to interfere with the formation of cartels.

This situation suggests that, at least in some instances, it may be difficult to ensure a competitive contracting environment. In certain cases, however, there may be steps that can be taken to increase competition. For example, Beenhakker (1987: 158) mentions that community organizations such as villages, tribes, religious groups, or nonprofit organizations can be potential suppliers of road maintenance. Allowing such groups to bid against normal private contractors may increase the degree of competition. Similarly, if some governmental organizations continue to provide maintenance, they too may bid for the right to maintain roads in another geographical area.

There are other issues concerning maintenance contracting that are not addressed in the literature. One pertains to the longer-term liability of contractors. While it may be simple to observe whether some maintenance tasks are or are not performed (for example, a culvert either is or is not cleaned or vegetation has or has not been cleared), not all maintenance is so easily observed (for example, whether proper techniques have been used to fill potholes). Ideally, contractors would be liable for failures that arise due to improper application of maintenance procedures. Such liability requires an adequate court system to ensure its enforcement and the ability to assess causality for road failures. While court systems in at least some developing countries may be adequate, two features of road deterioration that have been emphasized throughout this paper make assessment of causality extremely difficult. One is the relatively long amount of time required for poor or improper maintenance to make itself apparent; a second is that road deterioration can and will occur in spite of adequate maintenance. By the time the consequences of improper maintenance procedures make themselves apparent, the contractor may no longer be available to bear the consequences. Furthermore, it may be difficult, if not impossible, to determine whether it was improper maintenance or some combination of improper road use (such as overweight vehicles using the road or the weather) that was the actual cause of the road's deterioration.

A second issue is that the simple use of contracting to produce maintenance is not a sufficient condition to ensure that proper maintenance will occur. The contracting modality does *not* address the important decision of how much of the budget should be allocated to routine maintenance and how much should be allocated to periodic maintenance and reconstruction. Because it is administratively complex to write contracts for routine maintenance, there may be strong temptations to allocate the bulk of the funds for contracts to carry out periodic maintenance or reconstruction rather than routine maintenance. This is particularly the case at subnational levels, where resource availability is commonly very uncertain. Local governments may prefer to budget funds on a piecemeal basis, as money becomes available, rather than to budget amounts for the entire year. Periodic maintenance activities, such as resurfacing specific sections of a road, may be more conducive to an incremental budgeting environment than routine maintenance activities, which should be conducted throughout the fiscal year.

Experience suggests that contracting for road maintenance in developing countries has been generally successful. A World Bank review of nine different countries found that roads under contract were well-maintained in at least seven of them (Harral and Faiz, 1988:19). The authors concluded that "By and large, contract maintenance tends to be more cost-effective than maintenance by direct labor, and contractors have been attracted to maintenance opportunities, even in remote areas." Evidence from Ponta Grossa in Brazil indicated that force-account maintenance costs 60 percent more than that by contractors. Brazilian contractors usually outperformed the permanent work forces in terms of productivity, as well (Harral, et al., 1986:11-12). When problems developed, they were mostly due to mistakes on the part of the government concerned and, after being identified, were easily rectified.

To close this discussion of the production of road maintenance, it may be useful to briefly review the highlights of a road maintenance by contract effort currently underway in Pakistan.[26] The project, which is being implemented by Kampsax International, is jointly financed by the World Bank and the Government of Pakistan. Although the case is extremely interesting, it should be noted that it does not address the full range of management and finance issues raised in this paper. First, the approach actually resulted in some *centralization*, rather than decentralization, of maintenance planning efforts. Second, the effort involves a considerable amount of external oversight; whether similar efforts are sustainable without such oversight (and external financial support) remains to be seen. Third, the effort concerns the national highway system of Pakistan, consisting primarily of paved surfaces; whether a similar approach would be feasible for predominantly earthen, rural roads cannot be concluded from this review.

The national highway network of Pakistan consists of nearly 5,000 km of important highways throughout the country and includes a wide range of physical and climatic conditions. While the National Highways Board was established to take responsibility for upkeep and maintenance of the major national roads, provincial Communications and Works (C&W) Departments were generally relied upon to plan and execute minor rehabilitation and improvements on the national highways lying within their boundaries as well as to conduct routine and periodic maintenance.

After a review of the overall system and the capabilities of the provincial C&W's, Kampsax recommended that "National Highways Board should as from 1st July, 1987 take over from the Provincial C&W's the full and direct responsibility for and control of all maintenance activities on the national highways in the four Provinces" (ibid., 1-7). Implementation of this recommendation amounted to a greater centralization of the highway maintenance planning process. But whereas the individual C&W's had been executing maintenance through force account methods, the Kampsax recommendations also included a full-fledged contracting approach to maintenance.

[26] The material here and the page numbers cited in the text are taken primarily from Kampsax (1986). Additional information was obtained from personal interviews conducted with Kampsax and personnel of the Government of Pakistan.

Several aspects of this contracting scheme are of particular interest due to the incentives they provide. First, a two-tier system of contracting was proposed. *First-tier contracts* were for routine maintenance efforts. These were defined to be for "Those ordinary maintenance activities which are required one or more times each year to preserve pavements, structures, shoulders, drains and verges against the combined effects of traffic, climate and topography" (ibid., 1-4) and included activities that would be independent of traffic volumes, such as vegetation control, drain cleaning, and cleaning of traffic signs, as well as activities related to traffic volume, such as making minor repairs to shoulders, culverts, and bridges as well as repairing potholes and repairing pavement edges (ibid., 8-1). The contracts for routine maintenance were to include specification of each and every maintenance activity that was to be carried out over a particular stretch of the highway during the contract period. To provide incentives for local contractors, bids on these contracts were restricted to contractors living within the area through which the highway passed. It was felt that this arrangement would increase the likelihood that local pressures could be placed on the contractors to carry out their efforts properly. Furthermore, the simple nature of the activities to be conducted meant that small contractors could be competitive and effective.

Second-tier contracts were envisioned for more complex, periodic maintenance efforts. Periodic maintenance was defined to include "those activities which are required once every second or more years only to reinstate the pavements, structures, shoulders, drains and verges to the conditions they were in at the time of construction or reconstruction" (ibid., 1-4). These activities included repaving asphalt concrete, regravelling, and making major repairs to bridges and culverts (ibid., 8-4). Due to their greater technical complexity, bidders for these contracts were required to demonstrate greater technical competency and greater availability of capital. Specifically, these contractors had to be "organized and equipped for such work, especially for production of asphalt concrete mixer production and laying by mechanical means, and for surface dressing works" (ibid., 10-12). The provincial C&W's were permitted to bid for such contracts; interestingly, however, they apparently have generally been unsuccessful at winning the bids.

At the heart of the maintenance contracting procedure was a full inventory of every kilometer of the highway system, including information regarding the road surfaces, shoulders, culverts, traffic signs, access roads, etc. Surface roughness measures were also made for each portion of the network. Only from such a data base was it possible to specify the exact activities that were to be carried out. However, since there were obviously many more potential activities to be conducted than resources available to finance them, a prioritization method was necessary to determine which of the potential activities were justified. To make these decisions, the World Bank's Highway Design and Maintenance Standards Model, based on traffic use patterns and vehicle operating costs, was used to determine estimates of vehicle cost savings attributable to different maintenance efforts on the several portions of the highway system. In addition, unit maintenance costs were also determined for each province (since some input prices vary geographically).

Because of geographical differences in traffic patterns, road conditions, and maintenance costs, centralization rather than decentralization of the planning process was justified to obtain optimal system-wide allocations of effort. To achieve maintenance optimization throughout the highway network, the system-wide costs and benefits of maintenance efforts had to be estimated; procedures based on only portions of the network, e.g., within a single province, could have resulted in sub- or greater-than optimal spending on maintenance within particular portions of the network. One result of this centralized planning process, however, was that it ensured that some portion of the total amount available to the National Highways Board would be allocated to routine maintenance.

In carrying out the contracting process, detailed cost estimates were first made to ascertain what activities could be afforded, given budgetary constraints and maintenance needs. Tender offers were then drawn specifying exactly what activities a contractor would be expected to perform during the following fiscal year. Bidders were not, however, informed of these cost estimates in order to ensure price competition. This differs from the contracting procedures used in some countries, such as Bangladesh, where potential contractors are informed of the estimated costs made by the government's road engineers. In these instances, the resulting "bidding" process precludes price competition; the result is that the highway authority can be considerably more arbitrary and capricious in determining the ultimate winning bidder and may more easily collude with individual contractors.

The maintenance contracting effort in Pakistan provides a good example of the difficult tradeoffs that must be made in designing a maintenance program. In addition, it relies heavily on strong supervision of maintenance efforts and requires considerable data to implement. Determining whether this system could be modified for budgeting and planning rural road maintenance at the local level would be a logical next step in improving the overall effort to maintain roads in developing countries.

SECTION V

Summary

ENSURING that rural roads in developing countries are maintained is no simple task. Furthermore, the reasons for this difficulty transcend simple poverty, since there is evidence from the United States and other wealthier countries that road maintenance may be slighted in favor of other perceived needs. Still, the situation is probably even more critical in many developing countries where extremely large portions of the existing road networks are becoming so deteriorated that only with massive infusions of new investment and improved maintenance efforts will the roads be able to sustain economic development efforts.

The literature shows that roads can, in fact, yield significant benefits to users in developing countries and that roads constitute one critical portion of the public infrastructure needed to support development. That benefits from roads can exceed their costs means that road construction and maintenance *can* be affordable. The problems in ensuring that such maintenance actually occurs therefore stem primarily from the nature of the services roads provide and the series of decisions and actions undertaken before road maintenance activities are undertaken. While benefits may be generated from road maintenance activities, revenues must be available for maintenance services to be produced, the budget process must allocate the necessary funds for this purpose, and the inputs purchased for this activity must be combined and managed to yield road maintenance outputs.

In general, road services, particularly in rural areas, are not conducive to the exclusion of nonpayers; this limits the use of pricing mechanisms that ensure that benefits derived by users are transformed into the revenues necessary for the infrastructure's upkeep. The services from rural roads can, however, exhibit subtractability, at least in those cases where one vehicle's use of the road damages the road surface thereby diminishing the benefits available to other users. The complexity of road maintenance is further enhanced by the difficulty in measuring the benefits from such efforts, primarily because of the long-term nature of these payoffs, and the complexity involved in measuring the costs imposed by one user on other users. These attributes make the design of institutions capable of financing and managing road maintenance especially complex.

The one area in which considerable knowledge already exists concerning road maintenance is "how to do it." The science of road engineering is well-developed and has shown empirically what practices ought to be undertaken to keep roads functioning at close to optimal levels. This should not be construed to mean that these tasks are easy or even that the models explaining the deterioration of roads and how it might be retarded are simple. Numerous factors, some beyond the control of policymakers, interact to determine the state of a roadway at any point in time. Still, in general, the discussion contained in Section III demonstrates that the engineering-based knowledge is much more well-developed than are the methods available for road finance and road management.

In the case of road finance, there is more a lack of pragmatic suggestions of how resources might be mobilized to support road maintenance activities than there is of theoretical knowledge. Because of non-excludability, direct charges on individual road users are generally not feasible. Yet the theory of public finance shows that financing methods that do not reflect the costs of road usage can lead to significant economic losses. Again, the problems of measurability mentioned above mean that designing such instruments is not a simple task. Furthermore, when the road maintenance services are provided by subnational governments, the design of efficient financing mechanisms is even more complex.

Even the mobilization of resources is not a sufficient condition for the provision of an adequate level of road maintenance. There must also be a willingness on the part of the decision-making unit to allocate these funds for that use. Hence, budgeting for road maintenance is also a necessary requirement for such services to be provided. Problems of budgeting raise additional issues that relate to the nature of the benefits from road maintenance, particularly since the rates of road deterioration in the absence of maintenance may be slow and not easily recognized. In addition, the political and bureaucratic incentives inherent in most public decision-making bodies can be biased against the maintenance of existing infrastructure, further compounding the problem.

Finally, there are major management issues encountered in the production of road maintenance. In this paper we have focused on three of these management or institutional issues. One concerns the decentralization of the maintenance task. There is little doubt that decentralization of these tasks can provide considerable benefits; however, the difficulties of financing decentralization maintenance can impede the workability of such arrangements. A second management issue concerns the degree to which labor-intensive production techniques can be utilized in developing countries. Again, the literature is generally supportive of such production technologies; the problems then are providing the right incentives to encourage such production techniques. Finally, the feasibility of using private enterprise in producing (as opposed to providing) road maintenance services is a concern. Again, evidence suggests the potential for significant benefits from such arrangements, although there are potential limitations to private production, as well. Still, designing the appropriate institutions capable of providing decentralized, labor-intensive, private-enterprise based road maintenance is not a trivial task.

This review has suggested that developing sustainable investments in rural roads in developing countries is a major challenge. As is stressed in *Institutional Incentives and Rural Infrastructure Sustainability*, the incentives of the various actors involved in the myriad of road planning, design, construction, maintenance, financing, and use decisions are critical in determining the outcomes. Therefore, greater knowledge of these incentives is necessary, along with the ability to alter them in ways that lead to improved outcomes. Unfortunately, there are few good examples of highly successful experiences in the road sector from which lessons could be fully or partially transferred to other settings. This suggests that one important step in improving the state of rural roads in developing countries is to establish a broader data base from which to determine what does and does not work. Such a database should be constructed with particular attention to the incentives facing the providers, producers, financiers, and users of road building and maintenance efforts. We are confident that there are instances of successful long-term road development efforts; the task, that remains then, is to ascertain what sorts of institutional mechanisms were used to help create these successes.

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